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ANALYSIS OF SOURCE SEPARATE COLLECTION OF RECYCLABLE SOLID WASTE-SEPARATE COLLECTION STUDIES

SCS ENGINEERS, INCORPORATED

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This report summarizes a study that assesses the technical and economic feasibility of separately collecting recyclable materials from the home. Twenty-two communities practicing separate collection were studied and detailed case studies of each system were summarized. A computer model utilizing this data was formulated and sample cost projections using various operating parameters are presented. In addition, a study of twenty households was performed to quantify the time, cost, and storage impact on participating families. This report should be helpful to city governments interested in instituting separate collection programs for the recovery of recyclables from the waste stream.

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SEPARATE COLLECTION STUDIES

Final Report

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I

SUMMARY AND CONCLUSIONS

Household Separation

Householder cooperation is necessary for source separation of solid wastes. In order to quantify householder requirements, 20 volunteer households participated in special studies during a two month period. Although the sampling of households was too small to be representative of any specific municipality or region, the primary conclusion drawn with respect to householder efforts is of significance:

- Requirements for householder source separation consume minimal amounts of time and are not costly.

Separate Collection Considerations

Separate collection of recyclable material should be considered a subsystem of the on-going residential refuse collection system. There are two basic approaches to separate collection: (1) a separate truck (or trucks) designated for collection of separated materials, and (2) a rack (or racks) mounted on a truck to isolate separated materials from mixed refuse during collection. Regardless of approach, there are several conclusions that should be drawn upon:

- Public relations at the onset and during a separate collection program is of crucial importance to attain and retain citizen awareness and participation.
- Enactment of an anti-scavenger ordinance is necessary to provide a legal vehicle for curtailing unauthorized collection of separated materials.
- There is positive indication that community response to a separate collection program is related to the socio-economic status within the service area.

Separate Truck Approach

As the name implies, the separate truck approach entails the use of independent trucks and crews to collect recyclable materials. Depending on the ability of a municipality to divert labor and equipment from normal or reserve refuse collection operations, the frequency of separate collection may be varied. Alternatively, some municipalities contract with private parties for separate collection. The following conclusions were drawn from the 17 case studies made of the separate truck approach:

- Three noteworthy issues were associated with household participation: (1) mandatory or voluntary program status had little influence on householder participation in the case study communities, (2) householder participation increases with program duration, and (3) changing householder refuse set-out habits from on-property mixed refuse collection to curb collection for separate collection did not decrease participation.
- Separate collection frequency was related to quantities diverted from disposal. The quantity of recyclable waste separately collected increased as separate collection frequency increased, indicating a willingness of householders to separate larger quantities of recyclable waste if storage requirements are reduced.
- Separate truck startup costs were minimal in the case study communities. Modifications were made to existing collection systems, diversions made from other public works functions, or reserve forces were utilized as sources of labor and equipment for separate collection.
- For a municipality desiring to implement a separate collection program, wastepaper is the most economically feasible material to collect. Separate collection of glass and/or metal cannot be performed economically unless the municipality is able to absorb the equipment and labor costs through use of budgeted reserve forces.
- Separate truck collection of recyclable materials, as currently practiced, effectively reduced overall solid waste management costs. If rerouting of mixed refuse collection vehicles were performed to take advantage of lesser quantities of waste, additional cost savings could be obtained.

Rack Approach

The most appealing aspect of the rack approach was that mixed refuse and separated materials can be collected simultaneously by the same crew. Householder refuse set-out habits need not be altered. Based on five case studies made of the rack approach, the following conclusions were drawn:

- Startup costs for the rack approach are limited to rack fabrication and installation.
- The cost-effectiveness of the rack approach was dependent on the flexibility of the mixed refuse collection system to absorb incremental crew time requirements (placing material in rack; transferring material when racks filled prior to truck body filling with mixed refuse; and off-loading material at the disposal site prior to dumping mixed refuse) without creating a need for additional equipment and labor. Rack case study sites were able to absorb the incremental time requirements, and rack collection effectively reduced overall solid waste management costs.

II

INTRODUCTION

Increasing concern for protection of the environment and the need to conserve diminishing resources has revitalized interest in recovering resources from solid waste. Closely related to this renewed interest are projected depletion rates and/or demand exceeding supply of some natural resources. The paper industry, and, in particular, the newsprint faction are already succumbing to the pressures of supply and demand. During 1973, Canadian International Paper Company announced price increases totaling $35 per ton resulting in a January 1974 price of $200 per ton to United States consumers of newsprint.[1] This 21.2 percent rise is significantly higher than the annual industry average of 3.5 percent over the previous six years.[2] Newsprint price rises such as these are of great economic significance since an estimated 65 to 70 percent of all newsprint used in the United States is imported from Canada.[2]

Gauging the impact of supply and demand on domestically processed paper prices is difficult due to the price freeze. The U.S. Forest Service, however, has forecast a severe pinch on timber supplies (including paper) coupled with rapidly rising prices over the next few decades. As a result of higher prices and demand forecasts exceeding projected supplies, many newspaper publishers have announced cutbacks in the size of publications and will likely raise subscription fees and/or advertising rates.

In addition to projected virgin pulp shortages, increased demands for wastepaper from Far East and European markets have significantly influenced the value of domestic wastepaper.[2,3] For example, in April 1973 used wastepaper collected by municipalities was selling for under $10 per ton. As of March 1974, wastepaper prices were as high as $56 per ton in some areas of the United States.

Wastepaper price increases have not been mirrored by glass and metal container salvage prices. This situation, in conjunction with glass and metal representing smaller portions of residential solid waste, has resulted in wastepaper being most amenable to separate collection.

Closely paralleling the rise in wastepaper prices has been an increase in the number of separate collection programs. In 1967, the National Committee for Paper Stock Conservation (American Paper Institute) approached Madison, Wisconsin,

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concerning participation in a pilot project to salvage and recycle newsprint. Interests in increasing the supply of good paper stock complemented city attempts to reduce the solid waste volume entering the Madison sanitary landfill. Thus, in 1968, the pilot project was implemented in the eastern half of Madison with recovered tonnage averaging about 80 tons per month through 1969. Changes in collection procedures and expansion to a city-wide separate newspaper collection program saw salvaged quantities rise to an average of over 240 tons per month in 1972.

For several years after initiation of the Madison experiment, separate collection of recyclable materials was fairly dormant. From 1970 to the present, however, over 100 separate collection programs have been initiated with about three-fourths of this total originating since June 1973. It was with respect to the upsurge of separate collection programs that the U.S. Environmental Protection Agency, Office of Solid Waste Management Programs, Resource Recovery Division, contracted with SCS Engineers to obtain detailed information on the performance and costs of operating these resource recovery programs.

This report presents results of 22 case studies performed on separate collection programs throughout the nation. In addition to obtaining information on the recovery programs, information was also sought to determine the time requirements for householders to separate and prepare recyclable waste materials. Twenty SCS and EPA households conducted a two-month study of recyclable material separation. Results of the home studies are also reported.

The relationships developed and presented herein should be considered as best estimates from the empirical data available since many variables between case study locations could not be controlled.

III

HOUSEHOLD SEPARATION OF RECYCLABLE MATERIALS

Householder cooperation is necessary for source separation of solid wastes. Necessary householder activities are depicted in Figure 1 and are determined by material separation and preparation requirements of the separate collection service. For example, glass containers often must be cleaned, the metal rings removed, and sorted by color; newspapers often must be bundled or bagged; and metal containers may be accepted only if cleaned and crushed, the labels removed, and sorted by type of metal. Regardless of preparation requirements, all separated materials require interim storage at the home prior to separate collection.

In order to quantify those household waste activities, twenty SCS and EPA volunteer households participated in special studies.* General demographic information relevant to the participating households is summarized below:

- The median gross annual household income was about $20,000.
- Twelve participants resided in single family-detached houses, 5 in apartments, and 3 in condominiums/townhouses.
- The number of persons per household averaged 3.4.
- The household survey period ranged from 4 to 10 weeks and averaged 7 weeks.

Each household used prepared forms to record daily solid waste generation data relevant to five recyclable waste material categories:

- Glass (by color);
- Tin/bi-metal;
- Aluminum;
- Newspaper; and
- All other solid waste (excluding yard trimmings).

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*It should be noted that the findings presented in this section are derived from too small of a sample to be deemed representative of any specific municipality or region. Rather, the findings are presented for general interest and to express relative efforts and costs heretofore unquantified.

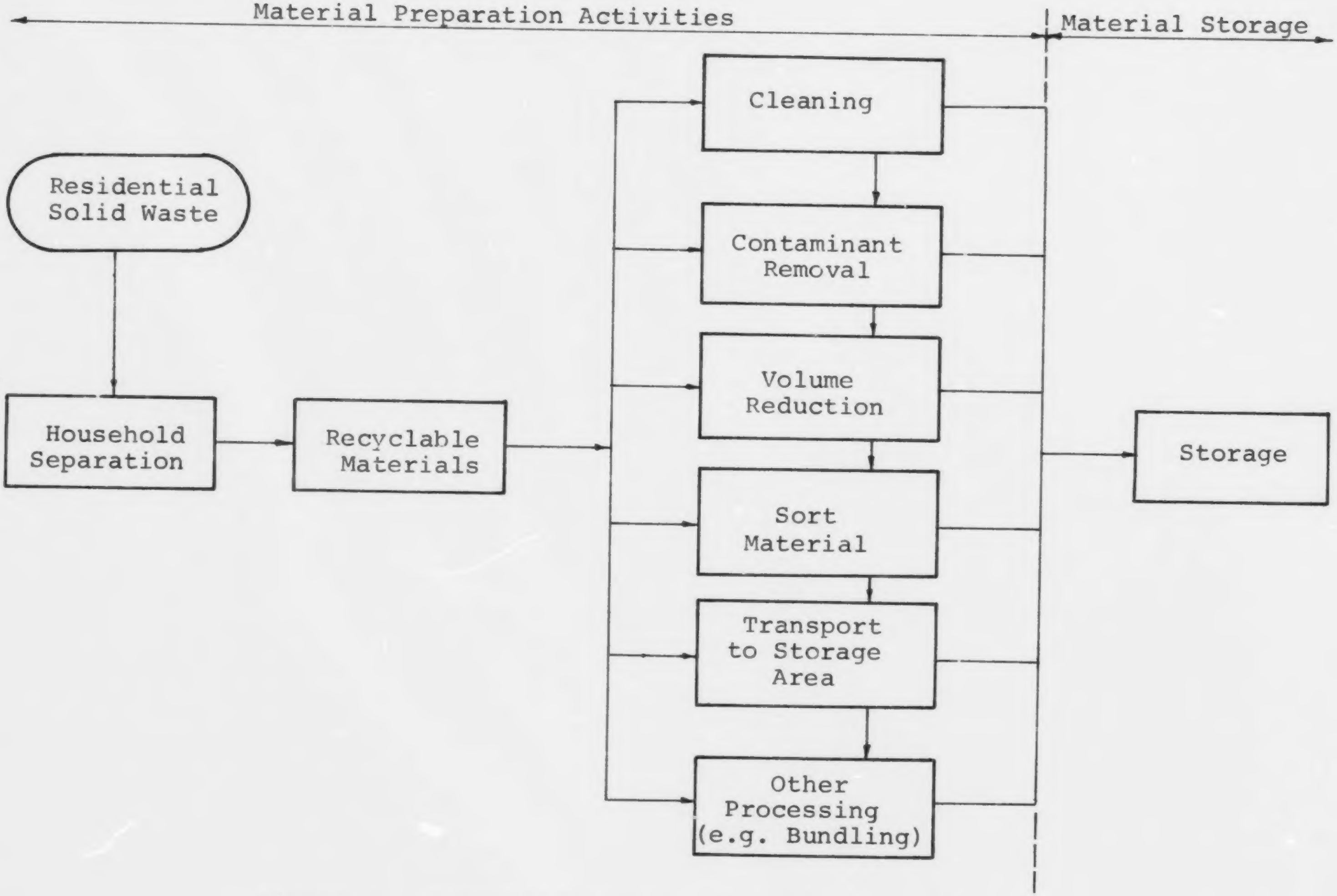
Material Preparation Activities
Material Storage
Residential Solid Waste
Household Separation
Recyclable Materials
Cleaning
Contaminant Removal
Volume Reduction
Sort Material
Transport to Storage Area
Other Processing (e.g. Bundling)
Storage

Figure 1. Household source separation activities.

The data forms were also used to record time requirements per material associated with the activities shown in Figure 1. Other data collected included storage requirements, supplies, and resources used (e.g., twine for bundling and water for cleaning).

Material Generation

Table 1 presents the average quantities of recyclable and non-recyclable materials generated per person per day, and per household per week. The definition for recyclable materials was based on an initial screening of over 60 recycling operations (separate collection programs and collection centers) and limited to those materials most commonly accepted (i.e., glass, tin/bi-metal, aluminum, and newspaper). Thus, excluding yard trimmings, non-recyclable materials were defined as all other residential solid waste. Potentially recyclable items such as corrugated cardboard, textiles, and possibly food wastes are admittedly penalized under this definition.

Tabular results show that nearly equivalent quantities of recyclable and non-recyclable materials were generated during the survey period.

TABLE 1

QUANTITIES OF RECYCLABLE AND NON-RECYCLABLE MATERIALS*

	Recyclable Materials (lbs)					Non-Recyl. Materials (lbs)	Total (lbs)
	Glass	Tin/Bi-Metal	Alum.	News-paper	Total		
lbs/cap/day	0.19	0.07	0.01	0.51	0.78	0.83	1.61
lbs/house-hold/wk	4.5	1.7	0.3	12.2	18.7	19.8	38.5

* Excludes yard trimmings.

Adding the daily per capita generation rates for recyclable materials (0.78 lbs) and non-recyclable materials (0.83 lbs) equates to a total of about 1.6 lbs for the participating households. This sum was significantly less than published national figures of 2.5 lbs per person per day, and a Los Angeles figure of 2.1 lbs per person per day (half of the household studies were conducted in the Los Angeles area). As previously defined, however, waste quantities excluded yard trimmings. In Los Angeles, yard trimmings comprise about 33 percent (by weight) of the total residential solid waste collected and disposed.[4]

Nationally, the American Public Works Association estimates that average municipal refuse contains 12 percent (by weight) of yard type waste.[5] The percentage expressed in terms of only the residential portion of municipal refuse would likely be higher. Thus, the overall generation rate recorded during the household study appears appropriate when all factors are considered.

Thus, separated material weight represented about one-third of the solid waste emitted from each household.

Material Preparation

Weekly time requirements per household for the activities associated with preparing recyclable materials for separate collection are summarized in Table 2. The total of 15.9 minutes per week to prepare all the materials averaged to about 2 minutes per day.

Table 3 presents a comparison of the preparation time requirements in terms of material quantity. Newspaper required the minimum amount of preparation time per unit weight of material and was, thus, the most efficient material for the householder to separate. In essence, bundling was the only significant time requirement. Bundling was normally accomplished in one of two ways: tying string or twine around newspapers, or stuffing newspapers in grocery bags.

Glass was the second most efficient material to separate. Cleaning and contaminant removal were the major time contributors. The least efficient materials to separate were metallic. Aluminum containers were low generation items although preparation time was proportionately high due to cleaning, contaminant removal, and volume reduction activities being performed prior to storage. Tin/bi-metal material preparation time requirements were highest because of time required to flatten containers. While aluminum containers were readily crushed, flattening tin/bi-metal containers necessitated removal of the can bottom.

TABLE 2

SUMMARY OF HOUSEHOLD TIME REQUIREMENTS FOR SOURCE SEPARATION

Material Preparation Operation	Average Preparation Time (Min/Wk)				
	Glass	Tin/Bi-Metal	Aluminum	Newspaper	Total
. Clean*	2.4	2.3	0.7	N.A.	5.4
. Contaminant removal	0.6	1.1	0.1	0.1	1.9
. Volume reduction	0.0	2.2	0.2	N.A.	2.4
. Bundle	N.A.	N.A.	N.A.	2.3	2.3
. Transport (in home)	1.6	1.4	0.3	0.6	3.9
Total	4.6	7.0	1.3	3.0	15.9

N.A. = Not Applicable

*Includes time for material sorting

TABLE 3

HOUSEHOLDER SEPARATION TIME REQUIREMENTS VERSUS QUANTITY OF RECYCLABLE MATERIAL GENERATED

Material	Householder Preparation Time (% of Total Time)	Quantity Separated (% of Total Weight)	Time to Weight Ratio
Glass	29	24	1.2
Tin/bi-metal	43	9	4.8
Aluminum	9	1	9.0
Newspaper	19	66	0.3

Viewed in terms of material value, (April 1973 revenue rates), Table 4 shows that preparation of newspaper and aluminum had greatest worth in terms of householder efforts-eight cents per min of preparation. Glass preparation had half of the newspaper/aluminum worth, while tin/bi-metal had the lowest worth ratio - less than a penny per min of householder effort. During 1974, revenue for newspaper and aluminum experienced appreciable increases. Newspaper, however, had a proportionately greater increase such that the monetary return on invested householder effort was greater. Thus, in terms of efficiency and worth, newspaper appears to be the optimum material in terms of householder source separation requirements.

TABLE 4

HOUSEHOLDER PREPARATION TIME VERSUS RECYCLABLE MATERIAL VALUE

Material	Material Value* ($/ton)		Householder Preparation Effort	Monetary Return on Householder Effort ($/min of effort)	
	April 1973	March 1974	(Min/Ton)	April 1973	March 1974
Glass	20	20	500	0.04	0.04
Tin/bi-metal	15	15	2,000	0.01	0.01
Aluminum	200	300#	2,600	0.08	0.12
Newspaper	8	30	100	0.08	0.30

*Based on typical revenue received by the case study collection centers for the dates indicated.

#Aluminum revenue increased from $200 to $300/ton in June 1974.

Material Preparation Costs. Material preparation costs were defined as the incremental costs incurred by a householder for supplies or resources used while separating and preparing recyclable materials. Included in this definition would be water used for cleaning, energy used if metal container volume reduction was accomplished with the aid of an electric can opener, and twine used when bundling newspapers. Implied costs of householder time were excluded.

Participants in the household study did not use soap for cleaning separated containers unless the soap was contained in used dishwater. Similarly, mechanical dishwashers were not used for cleaning containers. Thus, no incremental costs were assigned for soap or dishwasher use.

Incurred material preparation costs are presented in Table 5. The preparation cost per ton varied by material and ranged from zero when no preparation activities were performed to a high of about $2.30 per ton for cleaning and flattening aluminum containers. Expressed as a household cost per month, about $0.02 per month would be expended if all material were prepared for separate collection. A detailed derivation of the incurred costs is provided in Appendix A.

Comparing Tables 3, 4, and 5 presents an interesting inverse relationship. While newspapers were the most efficient and worthwhile material to separate, they were also the most costly to prepare. At about one penny per month, however, the cost of preparation should not deter household participation.

Material Storage

The floor area used to store separated materials during the household study was defined as the amount of floor space consumed by containers used to store materials or to stack newspapers. Consequently, the storage area requirement was a function of separated material generation rates and the accumulation time between removal by a separate collection program. The type of material and the amount of volume reduction practiced were also factors in storage area requirements. Newspapers, for example, when bundled and stacked, do not require any additional floor space for a one-week versus a one-month accumulation period. Glass accumulations, however, usually required additional floor space for storage as the accumulation period lengthens because it is potentially hazardous to practice glass volume reduction in the home. Tin/bi-metal and aluminum materials storage space requirements were dependent on the amount of volume reduction practiced.

TABLE 5

RECYCLABLE MATERIAL PREPARATION COSTS

Material	Range in Material Preparation Cost ($/ton)	Average Material Generation Rate* (lbs/mo)	Time Required to Accumulate One Ton of Material Per Household+ (mo)	Range in Material Preparation Cost ($/household/mo)
Glass	0 to 0.53	19.3	104	0 to 0.005
Tin/bi-metal	0 to 1.45	7.2	278	0 to 0.005
Aluminum	0 to 2.33	1.3	1,538	0 to 0.002
Newspaper	0 to 0.43	52.8	38	0 to 0.011

*Based on generation rates determined from household study.
+Rounded to nearest month.

Based on household study data, Table 6 presents the average floor space required for storage of each type of separated material. The household accumulation period averaged one month. Data were not amenable to further breakdown.

TABLE 6

RECYCLABLE MATERIAL STORAGE SPACE REQUIREMENTS
(One Month Accumulation Period)

Glass	Tin/Bi-Metal		Aluminum		Newspaper
(sq ft)	Volume Reduction (sq ft)	No Volume Reduction (sq ft)	Volume Reduction (sq ft)	No Volume Reduction (sq ft)	Stacked (sq ft)
2.2	1.6	2.8	1.8	1.9	3.3

Incurred Material Storage Costs. Based on the household study and information obtained during the nationwide case studies, storage containers used by householders for separated materials were generally of a makeshift nature (e.g., cardboard boxes or grocery bags). Similarly, existing space was used for storage of recyclable materials. Thus, for all practical purposes, there were no incremental costs incurred by householders for storage of separated materials.

IV

SEPARATE COLLECTION CONSIDERATIONS

Separate collection of recyclable material should be considered a subsystem of an on-going residential solid waste collection system. There are currently two basic approaches to separate collection: (1) a truck (or trucks) designated for independent collection of separated materials, and (2) a rack (or racks) mounted on a truck to isolate separated materials from the mixed refuse during collection. Case studies were made at 17 locations employing the separate truck approach and five locations using the rack approach.

The case study locations are identified in Table 7, along with the recyclable materials separately collected. The major portion of the case study results will be geared toward the paper programs. Not only were there more data available on the paper programs, but, as will be discussed, the paper programs appear to be the most economically feasible.

Prior to an assessment of the two alternative approaches to separate collection, an overview of considerations applicable to either approach will be presented. These include the rationale for initiating separate collection programs; socioeconomic considerations; public response; public relations; need for an anti-scavenger ordinance; and material preparation requirements.

Program Initiation

The source of motivation and reasons for implementing the 22 separate collection programs studied are summarized in Tables 8 and 9. Program motivation was influenced by local citizenry as much as by municipal officials. Academic and industrial sources provided lesser, but significant, motivation. Citizen movements were typically local ecology groups and/or civic interest groups such as the American Association of University Women, the League of Women Voters, and philanthropic or service clubs.

Seventy-three percent of the case study locations cited the desire to reduce solid waste quantities for disposal as the reason for starting separate collection. Assessment of community interest in recycling was the second most prevalent reason. The desire for financial profit from separate collection of recyclable materials was not cited as a reason for implementing the separate collection programs. The

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TABLE 7

SEPARATE COLLECTION CASE STUDY LOCATIONS

	Materials Separately Collected	
Case Study Type/Location	Paper	Glass/Metal
Separate Truck Approach		
Bedford, Mass.	X	X
Bowie, Md.	X	X
Briarcliff Manor, N.Y.	X	
Cincinnati, Oh.	X	
Dallas, Tex.	X	
Ft. Worth, Tex.	X	
Great Neck, N.Y.	X	
Green Bay, Wisc.	X	X
Greenbelt, Md.	X	
Hempstead, N.W.	X	
Marblehead, Mass.	X	X
Newton, Mass.	X	
Reston, Va.	X	
Tuscon, Ariz.	X	X
University Park, Tex.	X	
Villa Park, Ill.	X	
West Hartford, Conn.	X	
Rack Approach		
Chicago, Ill.	X	
Madison, Wisc.	X	
New York, N.Y.	X	
San Francisco, Calif.	X	
Sheboygan, Wisc.	X	

TABLE 8

SOURCE OF MOTIVATION FOR IMPLEMENTING SEPARATE COLLECTION PROGRAMS

Response	Source			
	Municipality	Citizenry	School	Industry
Number*	12	12	4	3
Percent**	55	55	18	14

*22 total respondents (i.e., case study sites). Multiple sources cause the sum to exceed the total number of respondents.

**Multiple responses cause the sum to exceed 100 percent.

TABLE 9

REASONS FOR IMPLEMENTING SEPARATE COLLECTION PROGRAMS

Response	Reason			
	Reduce Disposed Quantities	Assess Community Interest in Recycling	Combat Rising Solid Waste Management Costs	Demonstrate Municipal Environmental Concern
Number*	16	7	4	4
Percent**	73	32	18	18

*22 total respondents (i.e., case study sites). Multiple reasons cause the sum to exceed the total number of respondents.

**Multiple responses cause the sum to exceed 100 percent.

influx of about 100 separate collection programs from Fall 1973 through Spring of 1974, however, is likely related to a rise in recyclable paper prices-as much as $25 to $56 per ton depending on the local market conditions. Thus, economic considerations now probably play a more important role than indicated by the case study responses.

Socio-Economic Considerations

At the onset of the project, socio-economics were hypothesized as an explanatory variable for program success predictions. When the case studies were conducted, however, none of the selected sites were able to provide quantitative socio-economic information on the areas served by separate collection programs.* Qualitatively, only Green Bay, Wisconsin attributed participation rates to socio-economic criteria. In the Green Bay pilot area, 40 percent of the residents were designated as highly transient and of lower-middle economic status. The remainder of the pilot area was judged to have been 43 percent middle class and 17 percent upper class. Green Bay representatives stated that participation was less in the transient/low income sector when compared to the more affluent sectors of the pilot area.

Without quantitative data to analyze, a qualitative socio-economic assessment of each case study location was obtained where possible to reflect a cross-section of the area served by the separate collection program (i.e., lower, lower-middle, middle, upper-middle, or upper economic status). These assessments were compared to the program participation rate# with the results shown in Figure 2. As shown, there appears to be positive indication that socio-economic status is

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*Many of the separate collection service areas were not amenable to census data. As a result, knowledgeable personnel at each case study location were asked to assess the socio-economic status within the service area.

#Participation rate is defined as the number of householders, expressed as the percent of residents in a separate collection service area, placing recyclable material out for collection during the time of the case study.

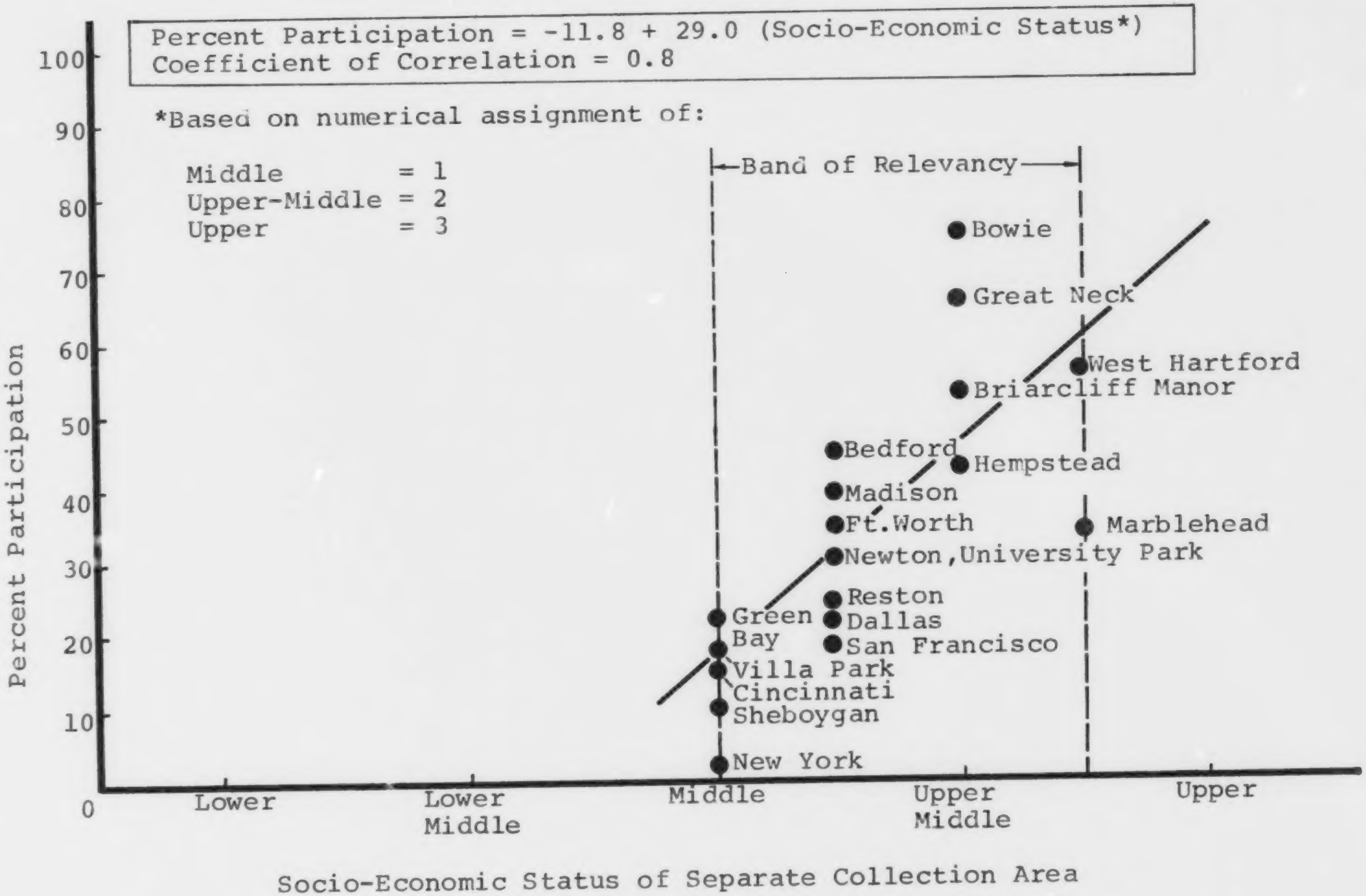

Figure 2: Participation rate as a function of socio-economic status

important to achieving program success.* Although the data plotted in Figure 2 is subjective, thus making the statistical validity shown questionable, the trend is of significance.

During the time between performance of the case studies and publication of this report, the University of Wisconsin graduate School of Business released the results of a socioeconomic study of voluntary users and non-users of the Madison recycling center and participation in the separate collection program.[6] The results are of significance and should be considered by communities when assessing the feasibility of a separate collection program. The study concluded that the major differences between users and non-users were:

- Over half the recycling center non-users had gross annual incomes of under $10,000 while the majority of the users earned over $14,000.
- Occupation of the family head was strongly related to recycling center use. Thirty-nine percent of the user family heads were professionals (i.e., lawyer, medical doctor, professor, engineer, etc.) as compared to 10 percent for the non-user families.
- Education of the family head and wives revealed the strongest relationship of user criteria examined. Seventy-three percent of the family heads and 59 percent of the wives in user homes had four or more years of college. Comparatively, 34 percent of the non-user family heads and 22 percent of the wives had four or more years of college. Further, 41 percent of the non-user family heads had four years of high school or less as compared to 13 percent of the user family heads.
- In terms of saving newspaper for the Madison separate collection program, education was strongly correlated. When the family head had four or more

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*Three programs were purposely excluded from Figure 2: The Greenbelt, Maryland program was not included due to municipal officials being unable to place any degree of confidence in the participation rate being attained due to a predominance of cluster housing and common collection points. The Chicago, Illinois program foundered due to scavenger problems and the Tucson, Arizona program was a subscription service.

> years of college, 93 percent saved newspapers for recycling. When the family head had four years of high school or less as a maximum education level, only 60 percent saved newspapers.

Two other points highlighted in the Madison study were also of interest: there was no relationship found between the number of children under 18 and use of the recycling center. Nor was age of the family head found to be a factor. The study had hypothesized that recycle center users would have more children and be younger. Neither hypothesis was supported by the study data.

In spite of the fact that family head age was not found to be significant in Madison, age may be influential in determining the amount of paper available for separate collection.

Although not a case study location, the Fullerton, California* separate newspaper collection program was observed during the first several months of operation. It was observed that areas of the city housing senior citizens were not generating newspaper at a rate proportional to the city as a whole. Although participating in the program, persons on fixed incomes or pensions appeared not to subscribe to daily newspapers to the normal degree. Paper placed out for collection was generally composed of a local weekly newspaper and "junk mail" printed on newsprint. This phenomena may be significant to a municipality assessing the feasibility of a separate collection program where a large portion of the residents are of the status described.

Public Response

Several attitudinal studies have measured the positive desires of householders to participate in recycling efforts by separating their refuse. For example:

- "Virtually all metropolitan housewives (90%) express willingness to separate their trash to facilitate recycling. About half feel that such activity should be mandatory rather than voluntary. Were separation of trash required, however, housewives claim they would prefer to have it done at the household level rather than pay even a minimal ($1-a-year) fee to the municipality to have it done for them."[7]

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*The Fullerton, California separate collection program commenced September 1973; after the case studies contributing to this report had been concluded.

- "While most Toledo, Ohio, residents appear unwilling to accept increases in family expenses or reduction in standard of living in order to minimize environmental pollution, an overwhelming majority would be willing to purchase only returnable beverage containers and separate paper and other refuse for recycling. Asked if they would be willing to separate their own trash into recyclable paper, cans, bottles, and garbage, 82% of the pollution-conscious group said yes, 12% were undecided and 6% said no. Of the less-concerned group, 91% said yes, none were undecided, and 9% said no. Of the less-concerned group, 93% said yes, none were undecided, and 7% said no."[8]

- A nationwide polling showed that 71% of the respondents were willing to collect and save old newspapers for recycling, while 55% were willing to sort trash at home to facilitate recycling.[9]

- Prior to implementing the separate newspaper collection program in the New York case study area, 20% of the householders indicated a desire to participate. The average participation rate achieved was 2% upon commencement of the rack program.

Overall, the 22 case study locations had participation rates ranging from 2 to 75 percent with an average of under 40 percent. Thus, it appears that a significant gap exists between what people say versus what they practice.

Public Relations

Public relations at the onset and during a separate collection program has been found necessary to attain and retain participation.

Announcements of the program should precede the implementation date by a month or more and outline the program goals, provide rationale for separate collection, present collection schedules, etc. During the interim period between initial announcement and implementation, continual reminders should be made through the local media (articles in newspapers, spot announcements on radio and television). In addition, notices in utility billings, printed door knob hangers, and announcements made to/by local civic/service groups are often used for initial and on-going publicity purposes.

Eleven of the 22 case study sites kept records of initial publicity costs (see Table 10). Promotional efforts were largely donated by civic-minded citizen/environmental groups; however, "out of pocket"* expenditures averaged 10 cents per household in the separate collection area with a range of a penny to 33 cents per household.

Although coincidental, a difference existed in initial publicity expenditures between the average separate truck program (5 cents per household) and the average rack program (15 cents per household). Initial publicity efforts for each differed only in the technique of distributing publicity materials to householders. The separate truck programs used a combination of mailing and distribution of door knob hangers and publicity flyers by youth groups. The youth groups were paid at the rate of about one cent per household. The three rack programs with cost records used city employees exclusively to distribute door knob hangers and flyers, thus accounting for the threefold cost difference.

None of the case study sites maintained appropriate cost records for on-going publicity efforts although each site stated the importance of constant public reminders. The effect of terminating publicity efforts following program initiation was demonstrated in the New York case study (Queens Sanitation District 67 only). An extensive initial publicity campaign resulted in 22 tons of separated newspaper the first month of the program. By the sixth month, however, quantities had declined to only three tons. Officials stated that publicity in Queens District 67 had lagged due to publicity requirements in other districts. The officials indicated that in other areas of the city, program participation would respond favorably to reminders and then tail off; thus indicating the need for a continuous publicity program.

There were several methods used by the case study programs for on-going publicity. Reminders in utility billings, weekly series in local papers, and program goals or themes were used effectively.

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*Out-of-pocket expenditures include only those costs incurred by the case study program. Donated time or inkind service costs were not quantified due to lack of data maintained at case study locations.

TABLE 10

INITIAL SEPARATE COLLECTION PUBLICITY COSTS

Case Study Location	Initial Cost* ($)	Residences in Separate Collection Area (No.)	Initial Cost Per Residence ($/Res)
Separate Truck Approach			
Bedford, Mass.	180	3,200	0.06
Ft. Worth, Tex.	1,000	22,620	0.04
Green Bay, Wisc.	400	2,000	0.20
Greenbelt, Md.	600	6,100	0.10
Marblehead, Mass.	400	7,600	0.05
Reston, Va.	65	7,550	0.01
University Park, Tex.	610	8,280	0.07
Villa Park, Ill.	50	6,470	0.01
Subtotal	$3,305	63,820	0.05
Rack Approach			
Chicago, Ill.	380	1,160	0.33
Madison, Wisc.	6,030	41,000	0.15
New York, N.Y.	2,400	15,350	0.16
Subtotal	$8,810	57,510	0.15
Total	$12,115	121,329	0.10

*Out-of-pocket costs only. Does not include costs for donated or inkind services or materials.

Scavenger* Problems

Scavenger problems have a higher probability of occurrence when market prices are high. With the recent rise in wastepaper prices, separate paper collection programs have become a target for many scavengers.

Scavenger problems were evident in Cincinnati, Hempstead, and Chicago. At the time of the case studies, Cincinnati had the highest revenue rate of any program visited - $14.20 per ton. Wastepaper dealers in Cincinnati reported a 100 percent increase in supply after implementation of the separate collection program, yet municipal trucks accounted for only 25 percent of the increase. Thus, program effectiveness, from the point of generating revenue for the city, was severly hampered. Cincinnati had no recourse as scavengers were licensed and within their rights to collect the separated paper prior to city collections being performed.

Scavenger problems were also critical in Chicago where again, no ordinances prohibited such activity. During three months of operation, less than 15 tons of newspaper had been collected by the municipality in a pilot area of about 3,000 residences. A survey of scavengers by city officials indicated that residential participation was as high as 75 percent at the onset of the program. City officials were not concerned that scavengers collected and sold the separated newspapers as the primary goal of the program was to reduce the volume of waste to be incinerated, not to obtain revenue from the sale of the newspaper.

Other case study locations had instituted ordinances making separated paper the property of the designated collector. Hempstead provided a good example of the effect of price rise on scavenger operations and the positive effect of an ordinance. At the time of the case study Hempstead was receiving $9 per ton for newspaper collected and delivered to the paperstock dealer. At the $9 price scavengers were not active. When paper prices reached $17 per ton, Hempstead began losing about 40 percent of the paper to scavengers (100 tons per month). To combat the problem, Hempstead implemented provisions of an existing scavenging ordinance. A crackdown was initiated by sanitation inspectors who patrolled the hardest hit areas at night and in the early morning hours in radio-equipped cars. Six summons were issued during the first month of patrol. The six cases were pending at the time of this report. If convicted, the scavengers can be fined $250 and receive up to 15 days in jail. The crackdown has resulted in a significant drop in scavenger activity.

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*In some locations, licensed haulers are designated as "scavengers." The scavengers referenced herein are unauthorized and, often, unlawful collectors of recyclable materials designated for separate collection.

Almost all separate collection programs can expect some scavenging. An anti-scavenger ordinance is therefore necessary as a legal vehicle to control scavenging activity. However, the manner and cost of policing the ordinance should be considered by program officials.

Material Preparation Requirements

Proper preparation of recyclable materials for separate collection is imperative for efficient operations. Preparation requirements were similar in the case study locations.

Paper. Preparation requirements for newspaper or mixed paper required the materials to be contaminant free and bundled with string/twine or stuffed into paper grocery bags.

Paper contamination is based on ultimate use. For example, if separated paper is to be reused as newsprint, paper products other than used newspaper would be contaminants. However, if the end use is combination board, insulation, or asphalt shingles, almost any form of wastepaper is acceptable (excluding wax or plastic coated paper products).

Bundling is required to minimize litter and to facilitate handling during collection. The impact of unbundled paper on collection operations was quantified during studies in Fort Worth, Texas.[7] Loading loose paper required from two to three times longer when compared to bundled paper.

Although not a case study site, portions of San Mateo County, California, receive separate newspaper collection service via the rack approach.* A spokesman for the collection firm commented on several drawbacks of using paper bags for bundling. Paper tends to slip out of the bag if not tightly stuffed, and the bag may rupture during handling operations (initial loading in racks, unloading racks, loading into transfer containers). These comments would also be applicable for collections using the separate truck approach -

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*San Mateo Scavenger Company, Inc., serving 11 cities and several unincorporated areas in San Mateo, California, initiated a separate newspaper collection program in November 1973.

more so with open truck operations than with enclosed compactor vehicles. Thus, the use of string/twine for bundling should be encouraged to facilitate efficient handling.

Glass. Glass preparation requirements entailed cleaning, color sorting, contaminant removal, and containerization prior to collection. Glass was normally collected at monthly intervals at the case study locations. Thus, cleaning was requested to eliminate pest and odor problems during storage.

Color sorting was almost always required as the color characteristics of recycled cullet often limit the flexibility of reuse.

Contamination of recyclable glass is virtually constrained to aluminum "neck rings" and metal foil hoods on some beverage containers. If allowed to enter the glass production process, these contaminants reduce final produce strength or cause color variations and, thus, must be removed.

Grocery bags were most commonly used as containers for separated glass. Although no time studies were performed for separate glass collection, the loose versus bundled paper collection analogy would certainly exist. Because ruptured bags could produce a hazardous collection condition, householders should be cautioned about using defective grocery bags and instructed not to overload a bag.

Metal. Although separated aluminum containers have a higher resale value than tin or bi-metal containers, the small quantities available per household did not generally warrant their independent separation. Metal preparation requirements generally consisted of cleaning, label removal, flattening, and containerization for ease of collection.

Cleaning was required for the reason previously stated - elimination of pest and odor problems during storage.

Label removal is a function of ultimate use. When label removal is required from tin containers, a chemical process is normally performed to recover the tin whereupon the stripped metal container is sold as scrap. If no label removal is required, tin/bi-metal containers are normally incinerated to remove labels and lacquered coatings with the resulting metal sold to the copper mining industry.

Flattening was required only to minimize storage space during collection when open trucks were used. When compactor trucks were used there was no requirement to flatten metal containers.

Again, metal separated for collection were required to be containerized. Grocery bags were most commonly used for this purpose.

V

SEPARATE COLLECTION: SEPARATE TRUCK APPROACH

As the name implies, the separate truck approach entails the use of independent trucks and crews to collect recyclable materials. Seventeen separate truck programs were studied to obtain operational and cost information. Table 11 provides descriptive information on the case study programs.

The population of the case study locations varied greatly: seven had populations of less than 25,000; five others ranged from 25,000 to 100,000; three had from 100,000 to 500,000 residents; and two were in the 500,000 to 1,000,000 population range. Of the five cities with total population greater than 100,000, only Cincinnati and Hempstead provided separate collection service to a major portion of the total. The programs in Dallas, Fort Worth, and Tucson were operated in pilot areas only. Full-scale programs were operated in all twelve locations with populations under 100,000.

The number of residents per household averaged about 3.6 in the separate collection areas. Socio-economic status of the separate collection areas reportedly ranged from middle to between upper-middle and upper.

Most of the programs were relatively new at the time of case study*: the duration of the average program was only about 14 months. Eight had been in operation one year or less, six others between one and two years. Only two had been operating for a two year or longer period.

Each separate truck program collected newspaper. Seven programs also accepted other recyclable wastepaper (corrugated cardboard, bond, etc.). Where mixed paper was collected, newspaper still comprised the bulk of the quantities available for collection. For example, in Fort Worth, the mixed paper quantities were estimated to be 80 percent newspaper, 15 percent corrugated cardboard, and 5 percent other recyclable paper. Only five locations collected glass and/or metal.

Separate collection responsibility was municipal in 11 locations while six were operated either by citizen groups,

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*Case studies were conducted in March and April 1973.

TABLE 11

SEPARATE TRUCK COLLECTION PROGRAM BACKGROUND

Case study location	Population (thousands)*		Program initiation data	Materials separately collected				Collection responsibility/ separation requirement##	
	Total	Served by sep. coll'n.		Newspaper	Other paper+	Glass	Metal	Municipal	Private
Bedford, Mass.	10	10	Nov. 1972	X	X	X	X		V
Bowie, Md.	40	40	Sept. 1971	X#		X	X	V	V#
Briarcliff Manor, N.Y.	10	10	June 1971	X					V
Cincinnati, Oh.	450	290	[illegible] 1972	X	X			V	
Dallas, Tex.**	900	60	March 1972	X				V	
Ft. Worth, Tex.**	400	90	Feb. 1972	X	X			V	
Great Neck, N.Y.++	10	10	Sept. 1972	X				M	
Green Bay, Wisc.**	90	90	May 1971	X		X	X	V	
Greenbelt, Md.	20	20	June 1971	X	X			V	
Hempstead, N.Y.	850	840	July 1972	X				M	
Marblehead, Mass.	20	20	April 1972	X	X	X	X	M	
Newton, Mass.	90	90	June 1971	X				V	
Reston, Va.	20	20	Feb. 1972	X					V
Tucson, Ariz.**	400	***	Aug. 1972	X			X		V
University Park, Tex.	20	20	March 1972	X	X			V	
Villa Park, Ill.	30	30	Dec. 1972	X	X				M
West Hartford, Conn.	70	70	March 1971	X				M	

*Rounded to nearest 10,000.
+Generally consisted of corrugated cardboard, bond, and magazines.
#Newspapers had been separately collected by scouting organizations four years prior to initiation of the separate glass/metal collection program in September 1971.
++Great Neck was selected to typify village operations within the town of North Hempstead, N.Y.; population 240,000.
**Program in pilot area only.
##M: Mandatory separation
V: Voluntary separation
***Less than 5,000 people.

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paper stock dealers or, in Tucson, by a newly formed private company. The Bowie program had both - glass and metal was separately collected by municipal crews, newspaper by a volunteer group.

The non-municipal approach was conducted in six relatively small communities (average population about 20,000). In communities of this size, volunteer groups or other private entrepreneur approaches may be feasible as equipment and manpower requirements are often small.

Five of the programs studied were legislated via a local ordinance which required householders to separate certain materials for collection. Twelve programs offered separate collection service to householders who voluntarily separated specified materials.

Separate Truck Activities

The activities associated with the separate truck approach are diagramed in Figure 3. The activites associated with the collection of recyclable paper differed somewhat from glass/metal container collections. The former were typically transported directly to the secondary materials dealer without interim processing or storage. However, the separate glass/metal collection programs stored materials until sufficient quantities had accumulated for efficient transport to a secondary materials dealer.

Green Bay was the only location practicing material processing - glass was crushed to increase density. This improved transport efficiency to the glass dealer located approximately 150 miles from the collection area.

Startup Costs

Startup costs in almost every location were negligible. Initial publicity costs averaged 5 cents per residence served. Initial equipment and labor costs were similarly low. In the case of private collectors, all collection vehicles (either open stake trucks or enclosed vans) were owned prior to commencement of the separate collection programs. The driver was either the owner or a full-time employee. Loaders were generally part-time employees hired on an "as needed" basis.

Municipal collection startup costs were similarly low. As shown in Table 12, Marblehead and Newton were the only municipalities requiring additional personnel for program

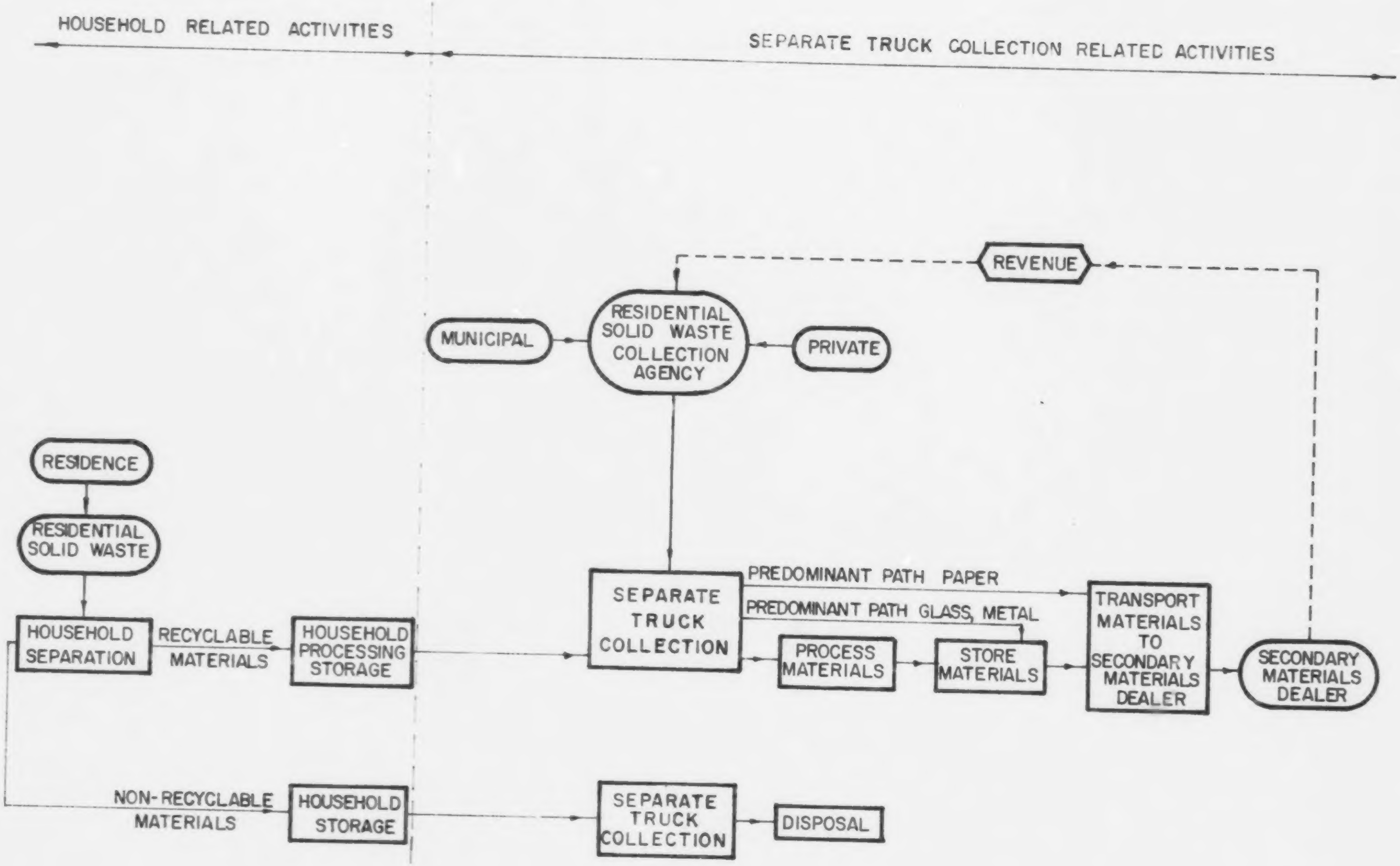
HOUSEHOLD RELATED ACTIVITIES
SEPARATE TRUCK COLLECTION RELATED ACTIVITIES
REVENUE
MUNICIPAL
RESIDENTIAL SOLID WASTE COLLECTION AGENCY
PRIVATE
RESIDENCE
RESIDENTIAL SOLID WASTE
HOUSEHOLD SEPARATION
RECYCLABLE MATERIALS
HOUSEHOLD PROCESSING STORAGE
SEPARATE TRUCK COLLECTION
PREDOMINANT PATH PAPER
PREDOMINANT PATH GLASS, METAL
PROCESS MATERIALS
STORE MATERIALS
TRANSPORT MATERIALS TO SECONDARY MATERIALS DEALER
SECONDARY MATERIALS DEALER
NON-RECYCLABLE MATERIALS
HOUSEHOLD STORAGE
SEPARATE TRUCK COLLECTION
DISPOSAL

Figure 3. Separate Truck Related Collection Activities

TABLE 12

SOURCE OF MANPOWER AND EQUIPMENT FOR IMPLEMENTATION OF MUNICIPAL SEPARATE TRUCK PROGRAMS

Case study location	Existing resources			Incremental requirements	
	Modification to existing solid waste collection system	Diverted from other public works functions	Reserve forces	Part-time labor	New equipment purchase
Bowie, Md.		X	X		
Cincinnati, Oh.			X		
Dallas, Tex.		X			
Ft. Worth, Tex.	X				
Great Neck, N.Y.		X			
Green Bay, Wisc.	X				
Greenbelt, Md.		X	X		
Hempstead, N.Y.			X		
Marblehead, Mass.			X	X	
Newton, Mass.			X	X	
University Park, Tex.		X			
West Hartford, Conn.	X				X

implementation (both locations used part-time hires to supplement existing crews); and only the West Hartford program required the purchase of incremental equipment (a 20 cu yd rear-loading compactor). In every other municipal case study location, either modifications had been made to existing collection methods, thus freeing crews and equipment for separate collection; equipment and labor had been diverted from other public works functions; or reserve equipment and labor forces were utilized.

For example, Fort Worth modified mixed collections to provide curb service using plastic bags rather than backyard service. A surplus in collection equipment and labor resulted, and two crews were diverted for a pilot separate collection program. Dallas and University Park both collected residential refuse four days per week with necessary brush and bulky collections made on Wednesdays by part of the brush collection crew. These crews were also used for the respective separate collection programs. Cincinnati was one of six municipalities to use reserve equipment and labor for separate collections.

Although the minimal case study startup costs present an optimistic outlook, there is a limit to which trucks and crews can be diverted from regular duties. The limit will vary from location to location thus requiring an individual assessment. For example, the pilot program in Fort Worth initially employed two extra crews for separate collections. The pilot program proved to be a success and a city-wide program was planned for June 1974 implementation. However, the city-wide expansion will not benefit from the previously described system modification; thus, new trucks have been ordered specifically for separate collection.

Equipment and Manpower Utilization

The respective resources used for municipal and private party separate truck programs are summarized in Tables 13 and 14. Municipal programs used rear-loading compactor trucks almost exclusively*, with capacities ranging from 10 to 28 cu yd. The non-compacting vehicles listed were usually borrowed from other public works functions when

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*The only adverse comment to the use of compactors for separate collection was voiced in Green Bay. A program official stated that small fragments were often ejected when glass was being compacted. This comment was not echoed in Marblehead, however, (the only other site to use a compactor for collecting glass).

TABLE 13

SEPARATE TRUCK COLLECTION EQUIPMENT
AND MANPOWER SUMMARY

-MUNICIPAL PROGRAMS-

Case Study Location	No. Vehicles	Vehicle Capacity* (cu yd)	Crew Size	Material Collected+
Bowie, Md.	1	20	3	M
	1	2½-ton open	3	G
Cincinati, Oh.	6	16	2	P
Dallas, Tex.	9	20	2	N
Fort Worth, Tex.	2	20	3	P
Great Neck, N.Y.	1	Dump truck	3	N
	2	Jeep	2	N
Green Bay, Wisc.	5	16	3	G,M,N
Greenbelt, Md.	1	16	3	P
	1	1½-ton open	2	P
Hempstead, N.Y.	6	20	3	N
Marblehead, Mass.	2	16	3	G,M,P
Newton, Mass.	1	16	3	N
University Park, Tex.	1	10	3	P
	4	28	3	P
West Hartford, Conn.	2	20	3	N
Average (compactor only)		18.6	2.8	

*Rear-loading compactor vehicle unless otherwise identified.

+G: Glass
M: Metal
N: Newspaper only
P: Mixed paper

TABLE 14

SEPARATE TRUCK COLLECTION EQUIPMENT AND MANPOWER SUMMARY

-PRIVATE PARTY PROGRAMS-

Case Study Location	No. Vehicles	Vehicle Description	Crew Size	Material Collected*
Bedford, Mass.	1	6'x 6' open	3	G,M,P
Briarcliff Manor, N.Y.	1	5 ton open	3	N
Reston, Va.	2	20 cu yd open	4	N
Tucson, Ariz.	2	Standard van	1	M,P
Villa Park, Ill.	1	3-1/2 ton van	4	P
Average			3.0	

*G: Glass
M: Metal
N: Newspaper only
P: Mixed paper

compactors could not be spared for separate collection. Conversely, private party locations used non-compactor vehicles exclusively.

The relationship between the number of trucks used for separate collections and the number used for mixed refuse collections was examined at the municipally operated case study locations. As depicted in Table 15, no conclusive relationships could be identified due to the diversity of variables between locations (e.g., collection frequency and pickup point for recyclables as compared to mixed refuse). Based on the case study relationships, however, a crude indication of relative equipment assignment for regular versus separate collection trucks shows approximate ratios of 5:1 for once per week wastepaper collection to over 20:1 for once per month collection although both higher and lower ratios were computed.

All municipal case study locations provided curb service for recyclable materials. Due to the small quantities of recyclable material (as compared to mixed waste), on-property collection using the separate truck approach expectedly would not be cost-effective. However, in spite of the curb collection point and the use of compactor vehicles, separate collection crews generally were too large. Crew sizes for municipally operated separate collection operations remained the same as those for mixed refuse collection crews; an average of 2.8 per truck. In view of the following conditions generally observed during the case studies, crews in excess of two on a rear-loading compactor are considered excessive:

- Separate collections were made from the curb.
- Where more than one category of recyclable material was acceptable (i.e., glass, metal, paper), each material type was independently collected (e.g., glass during the first week of the month, metal during the second, etc.).
- Comparatively small quantities of recyclable material (versus mixed waste) were collected at each stop.
- Containers for recyclable materials are classified as "one way items" (i.e., storage containers were not returned to the curb).
- Participation rates were substantially less than 100 percent, thus travel time and distances between collection points was in excess of normal collection.

TABLE 15

RATIO OF MIXED TO SEPARATE COLLECTION TRUCKS

Case Study Location	Collection Point		Mixed Refuse Collection Frequency (collections/wk)	Ratio of Collection Vehicles Mixed Mixed Trucks* : Separate Trucks (By Separate Collection Frequency)		
	Mixed Refuse	Separated Materials		1/wk	1/2 wk	1/mo
Bowie, Md.	Curb	Curb	2			13:1
Cincinnati, Oh.	Curb-35% Property-65%	Curb	1	6:1		
Dallas, Tex.	Curb	Curb	2	2:1		
Ft. Worth, Tex.	Curb	Curb	2	5:1	10:1	
Great Neck, N.Y.	Property	Curb	3			25:1
Greenbelt, Md.	Curb	Curb	3	5:1		
Hempstead, N.Y.	Curb	Curb	2	10:1		
Marblehead, Mass.	Curb	Curb	2	2:1		
Newton, Mass.	Curb	Curb	1			20:1
University Park, Tex.	Alley	Curb	2	3:1		
West Hartford, Conn.	Property	Curb	1		7:1	

*On-line trucks only.

None of the case study locations employed the economical one-man operated side-loading vehicle for separate collections, whereas the above conditions would appear to favor application of this method.

With the exception of Tucson, curb collection services were similarly provided by private party collectors. Crew sizes averaged 3 per vehicle, not unreasonable for open type vehicles used in these locations. Use of non-compacting vehicles required careful use of available space. Consequently, paper was usually stacked and glass/metal often containerized in 55 gal drums placed on the truck bed to keep materials separate and facilitate offloading. Therefore, a driver, loader, and stacker were justifiably used.

Time-motion studies[10] performed in Fort Worth also pointed to the excessive size of compactor crews used for separate collection. Separately collected wastepaper in Fort Worth was estimated to have a compacted density of about 650 lbs/cu yd. Based on limited weighings conducted during the household study, the same density was achieved via simple bundling of stacked newspaper. Whereas retention of bundled density on an open truck requires labor for stacking, the compaction mechanism should replace the need for the equivalent of this stacking labor.

Separate Truck Program Performance*

Separate truck program performance can be measured in several ways: participation achieved, waste quantities diverted, and collection productivity. Participation rates and diverted disposal quantities appear to be related. Together with collection productivity and revenues for collected material, they largely determine the economic viability of a separate collection program.

Prior to assessing performance, however, participation requires definition. Only two case study locations had estimates of the total amount of recyclable materials of various types entering the solid waste stream. Consequently, recovery rates were not available in total or on a material by material basis.# Thus, each location was requested to provide an estimate of householder participation at the time of the case study visit. Participation was defined as the percent of householders in a separate collection area placing out recyclable materials on a given collection day. With few exceptions, the data or estimates provided by each case study location consistent with this definition were used throughout this report wherever participation rate is discussed.[*]

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*Program performances measured in this section are influenced by such interrelated factors as community socio-economics and initial and on-going public relations. In fact, these factors may impact more on performance criteria than the specific approach to separate collection (i.e., separate truck or rack).

#Separated materials as a percent of total waste disposal were estimable, and will be discussed.

Participation. Participation is a necessary ingredient for program success. At the onset of the study, frequent separate collections and/or mandatory separation were hypothesized as necessary to maximize program participation. The 17 case studies contained a mix of mandatory and voluntary programs, and had collection frequencies ranging from once per week to once per month. Only Fort Worth operated a program with two different collection frequencies under similar conditions within the same city. In Fort Worth, the once per week separate collection service achieved a 40 percent participation rate, while the areas receiving service every other week participated at only a 25 percent rate.

The Fort Worth results, taken independently, tend to support a hypothesis that more frequent collection will increase level of participation. In order to further test the hypothesis, participation rates achieved by all wastepaper programs[#] were plotted as a function of collection frequency in Figure 4. Mandatory or voluntary program identification is also provided. Although there may be some credance to the hypothesis, participation must also be a function of

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[*] Exceptions to this definition were when quantities recovered were noticeably out of proportion with participation estimates. In such cases, participation rates were adjusted to reflect a more meaningful estimate. For example, Hempstead, New York officials estimated participation at about 80 percent. The 80 percent estimate was based on participation prior to increasing the area served by separate collection. The 80 percent estimate was not supported by the per capita newspaper generation statistics provided by Hempstead. Based on the overall data provided, a 42 percent participation rate was estimated for the total collection area.

[#] The wastepaper constraint was placed on the test in an attempt to achieve homogeneity in the results. In case study locations where wastepaper and glass/metal were separately collected, wastepaper programs generally achieved a higher participation rate. Ease of wastepaper separation and preparation was cited for the difference.

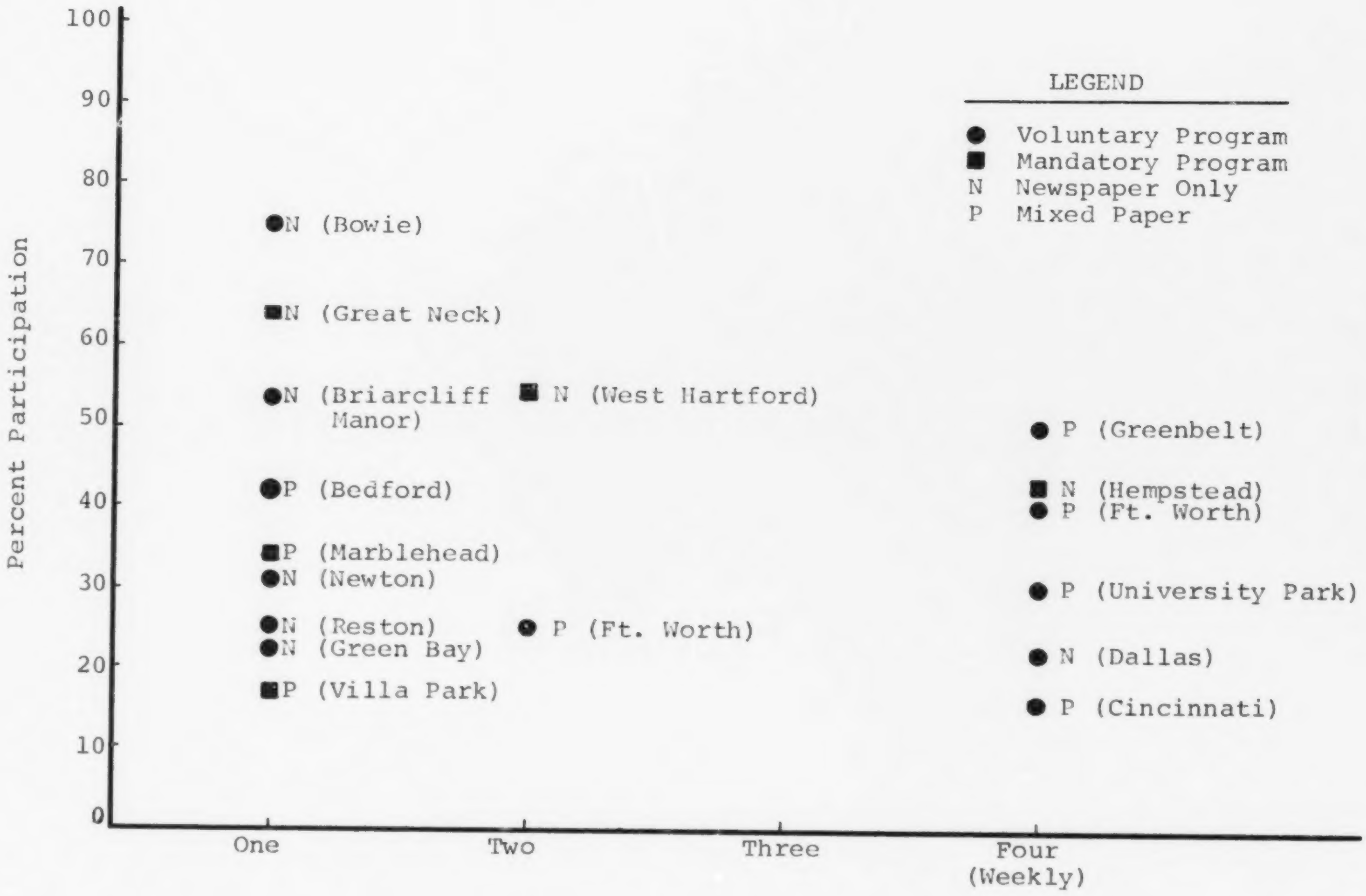

Figure 4: Participation rate as a function of separate collection frequency

other variables such as community socio-economics and public relations as discussed earlier. Several bi-weekly and monthly programs had greater participation rates than did the weekly programs; and mandatory rates were exceeded by voluntary rates in some locations. Also evidenced is the trend of newspaper programs to exceed mixed paper programs in achieving participation. Ease of newspaper separation is believed to be the primary reason for this disparity.

By replotting participation rates in terms of the separate collection program duration (Figure 5), a more positive relationship is indicated. Figure 5 indicates an expected increase in participation of about 18 percent annually based on case study location conditions.

In general, a voluntary program is recommended at program inception. By using voluntary participation as a barometer of public acceptance, the effectiveness of a mandatory program can be properly assessed. Great Neck, Hempstead, and West Hartford each initiated separate newspaper collection on a voluntary basis and adopted a mandatory ordinance after the program was well received by the populace. Greenbelt, following a successful voluntary program, was in the process of making mixed paper separation mandatory at the time of the case study. Villa Park and Marblehead may typify the reaction to newly mandated paper separation ordinances. Although these two programs can be expected to grow, they exemplify that an ordinance, by itself, does not guarantee higher participation.

A change in pickup location for materials was also considered as possibly adversely affecting participation. Three locations, Briarcliff Manor, Great Neck, and West Hartford, provided on-property service for mixed refuse collection while newspapers were required to be placed at the curb by the householder for separate collection. However, participation rates in these communities were among the highest. The communities were relatively small (population ranging from 7,500 to 70,000) and ranked among the highest in socio-economic status; therefore, participation might be expected to be high. Although only slightly lower on the socio-economic scale, University Park (population 20,000) achieved average participation rates even though residents were required to place recyclable materials at the curb rather than at the normal alley location for mixed refuse.

How a large municipality would be affected by a change in pickup location is difficult to generalize although the experience of the above four communities is encouraging.

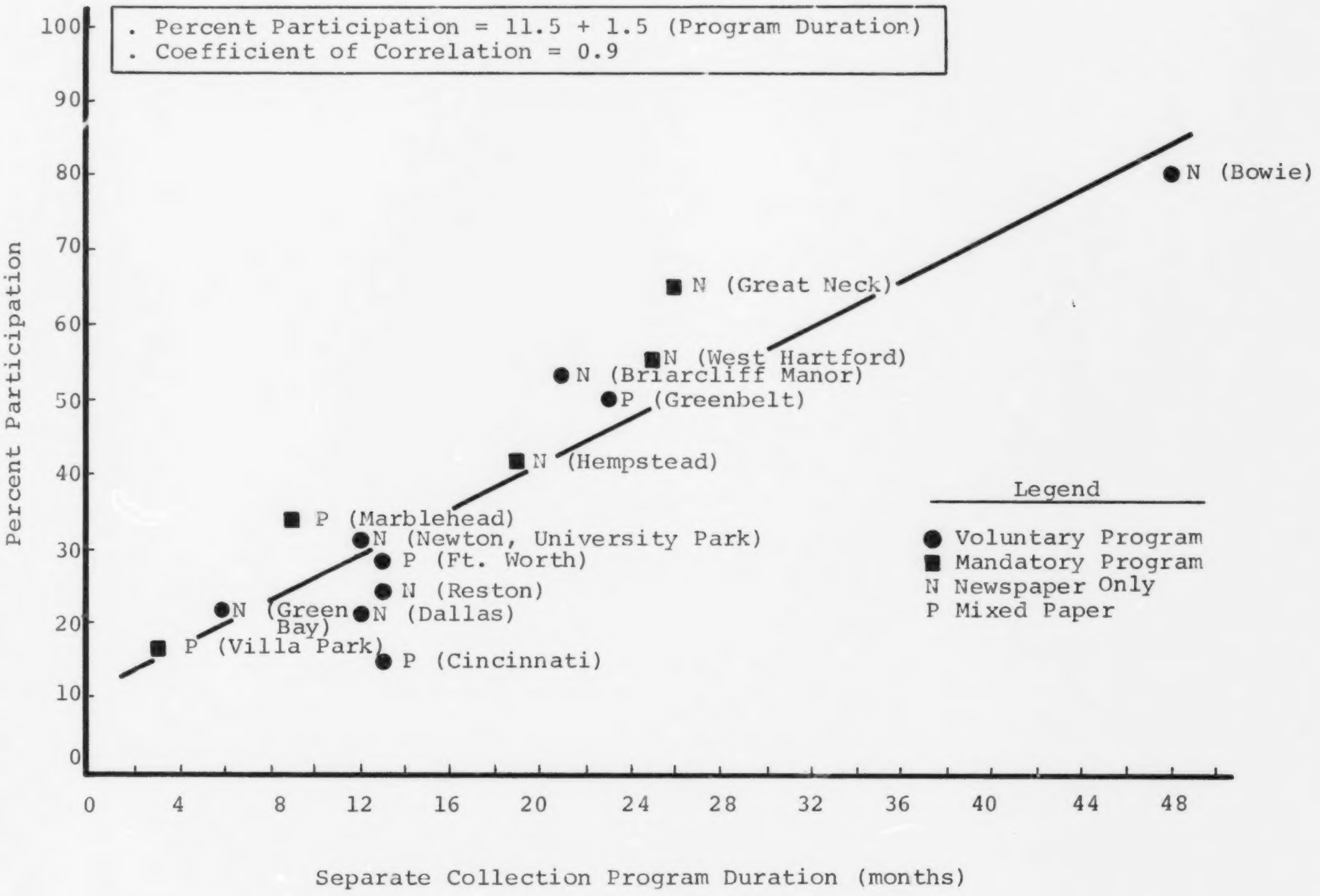

Figure 5 · Participation rate as a function of program duration.

Diverted Disposal Quantities. As previously noted, a desire to reduce waste quantities disposed was stated as being a primary motivation for activation of many of the studied separate collection programs. The relationship between collection frequency and program performance in terms of diverted disposal quantities was investigated.

Wastepaper collection frequency was related to waste quantities diverted from disposal. Although the average participation of weekly, bi-weekly, and monthly programs was virtually the same (see Table 16), weekly programs had an average diverted disposal quantity of over 7 percent versus 6 percent for bi-weekly programs and about 3 percent for monthly programs. Thus, a positive relationship appears to exist: diverted disposal quantities increased as collection frequency increased.

This frequency/diverted disposal relationship was reinforced by studies performed in the Fort Worth pilot areas.[10] The average participant in the weekly collection area placed out 21.0 lbs of mixed paper for collection. Comparatively, bi-weekly participants placed out 30.6 lbs, or an average of only 15.3 lbs per week. Apparently householders are willing to separate a larger portion of their recyclable wastes if storage time is reduced, that is, if separated materials are collected more frequently.

Diverted disposal quantities were not affected by mandatory/voluntary program status in the case study communities. The voluntary programs experienced an average diverted disposal rate of 5.4 percent versus a rate of 6.6 percent for the mandatory programs. The mandatory programs, however, were strongly influenced by the Hempstead program. Excluding Hempstead, the mandatory programs diverted 5.2 percent, similar to the rate achieved by the voluntary programs. Although these results may be biased by uncontrollable case study idiosyncracies, this comparison seems to further de-emphasize the importance of a separate collection mandate for program success.

Table 17 compares program participation by type of recyclable material and the quantity of material diverted from disposal. As seen, the average participation rate in newspaper only programs was 42 percent. Mixed paper programs averaged 32 percent participation while glass/metal programs had average participation rates of 31 and 25 percent, respectively.

The newspaper programs diverted about 6 percent of the total residential solid waste from disposal while mixed paper programs diverted almost 7 percent. One should not necessarily conclude that mixed paper programs divert greater quantities

TABLE 16

DIVERTED DISPOSAL AS A FUNCTION OF SEPARATE COLLECTION FREQUENCY
-WASTEPAPER PROGRAMS-

Case study location*	Participation rate (%)	Average quantities collected: Total residential refuse (tons/mo)	Average quantities collected: Separated paper (tons/mo)	Disposal reduction (% by weight)
1/mo Collection Frequency				
Bowie, Md.	75	1,560	31	2.0
Briarcliff Manor, N.Y.	53	280	22	7.9
Great Neck, N.Y.	64	480	28	5.8
Green Bay, Wisc.+	22	260	7	2.7
Marblehead, Mass.	33	1,040	46	4.4
Newton, Mass.	30	4,300	121	2.8
Villa Park, Ill.	17	970	35	3.6
Total/Average	39	8,890	290	3.3
1/2 wk Collection Frequency				
Ft. Worth, Tex.+,#	25	2,020	131	6.5
West Hartford, Conn.	54	3,810	220	5.8
Total/Average	41	5,830	351	6.0
1/wk Collection Frequency				
Bedford, Mass.	45	560	56	10.0
Cincinnati, Oh.**	15	10,580	167	1.6
Dallas, Tex.+	22	2,300	145	6.3
Ft. Worth, Tex.+,#	40	1,080	154	11.6
Greenbelt, Md.	50	440	32	7.3
Hempstead, N.Y.	42	11,370	813	7.2
University Park, Tex.	30	1,930	100	5.2
Total/Average++	39	17,680	1,300	7.4
Combined Total/Average++	39	32,400	1,941	6.0

*Reston, Va., and Tucson, Ariz. not included due to absence of applicable data.
+Program in pilot area only.
#Two pilot areas.
**Severe scavenger problem. Data accounts only for paper collected by municipality.
++Does not include Cincinnati due to scavenger problem.

TABLE 17

PERFORMANCE PROFILES FOR SEPARATE TRUCK CASE STUDY LOCATIONS

Case study location*	Participation rate (%)	Average quantities collected (tons/mo) Total residential refuse	Separated material	Disposal reduction (% by weight)
Newspaper Only Programs				
Bowie, Md.	75	1,560	31	2.0
Briarcliff Manor, N.Y.	53	280	22	7.9
Dallas, Tex.[#]	22	2,300	145	6.3
Great Neck, N.Y.	64	480	28	5.8
Green Bay, Wisc.[#]	22	260	7	2.7
Hempstead, N.Y.	42	11,370	813	7.2
Newton, Mass.	30	4,300	121	2.8
West Hartford, Conn.	54	3,810	220	5.8
Total/Average	42	24,460	1,387	5.7
Mixed Paper Programs				
Bedford, Mass.	42	560	56	10.0
Cincinnati, Oh.[+]	15	10,580	167	1.6
Ft. Worth, Tex.[#]	25,40[##]	3,100	285	9.2
Greenbelt, Md.	50	440	32	7.3
Marblehead, Mass.	33	1,040	46	4.4
University Park, Tex.	30	1,930	100	5.2
Villa Park, Ill.	17	970	35	3.6
Total/Average**	32	8,040	554	6.9
Combined Total/ Average: Paper**	39	32,400	1,941	6.0

TABLE 17 (Continued)

Case study location*	Participation rate (%)	Average quantities collected (tons/mo) Total residential refuse	Separated material	Disposal reduction (% by weight)
Glass Programs				
Bedford, Mass.	42	560	28	5.0
Bowie, Md.	7	1,650	9	0.5
Green Bay, Wisc.	31	260	6	2.3
Marblehead, Mass.	22	1,040	32	3.0
Total/Average***	31	1,860	66	3.5
Metal Programs				
Bedford, Mass.	42	560	5	0.9
Bowie, Md.	7	1,650	3	0.2
Green Bay, Wisc.	31	260	3	1.2
Marblehead, Mass.	17	1,040	11	1.1
Total/Average***	25	1,860	19	1.0
Combined Total/Average: All Programs**,++	###	32,400	2,089	6.4

*Reston, Va. and Tucson, Ariz. not included due to absence of applicable data.

+Severe scavenger problem. Data accounts only for paper collected by municipality.

#Program in pilot area only.

##Two pilot areas. 25% participation in bi-weekly areas; 40% participation in weekly collection area.

**Does not include Cincinnati due to scavenger problem.

++Multiple material programs not double counted to derive totals/averages.

***Does not include Bowie for reasons discussed in text.

###Average participation cannot be accurately determined due to unknown interface of participants in multi-material programs.

of waste at less participation than newspaper only programs since six of the eight newspaper programs had collection frequencies of once per month, while five of the seven mixed paper programs received weekly service.

Glass and metal programs had disposal diversion rates of 2 and 0.6 percent, respectively. Without the Bowie program, the diversion rates increased to an average of 3.5 percent for glass and 1 percent for metal. The Bowie glass and metal diversion rates are discounted because:

- Bowie achieved notariety by pioneering legislative efforts to outlaw non-returnable beverage containers. While the constitutionality of the ordinance was being tested, the glass and metal container separate collection program was initiated.
- The Bowie newspaper program achieved a reported participation rate of about 75 percent with once per month collection, while the glass/metal program received only 7 percent participation with weekly collection.

It is believed the general populace may have curtailed purchasing non-returnable containers because of the legislative effort - thus quantities of glass and metal would be low. The participation rates are questionable because of their variance with experiences of other locations.

An interesting relationship which may have socio-economic implications was provided by the Green Bay, Wisconsin case study. The Green Bay program required participants to accumulate separated materials for a month: metal was collected during the first full week of the month, glass during the second, and newspaper during the third week.* In that collection frequency is equivalent for each material, equivalent participation or a higher rate for newspaper due to ease of separation, might be anticipated. However, participation in the glass/metal portions of the separate collection program was reportedly 31 percent versus 22 percent in the newspaper portion. Forty percent of the residents in the Green Bay pilot area were identified as lower-middle class and transient. The number of regular subscribers to a newspaper could be lower for this group.

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*Marblehead, Massachusetts, had a similar separate collection scheme: mixed paper during the first week, metal during the second, clear glass during the third, and green glass during the fourth.

Aside from Bowie, the three multi-material programs - Bedford, Green Bay, and Marblehead - had an average diverted disposal rate of about 10 percent, significantly higher than wastepaper only programs were able to achieve. The average, however, is on the prorated average of three sporadic test programs conducted in Bedford whereupon almost 16 percent of the total residential solid waste generated was diverted. Thus, the 8 percent diversion rate in Green Bay and Marblehead may be more typical.

Collection Productivity. Collection productivity in the separate collection area was expressed in tons of recyclable material per separate collection truck per day. The productivity factors are summarized with respect to the wastepaper programs in Table 18. As shown, collection productivity averaged between five and six tons per truck per day regardless of collection frequency.

The productivity comparisons of glass and metal operations were limited to Bowie, Green Bay, and Marblehead. Bowie collected glass and metal weekly while the other two locations provided once per month service with productivity factors summarized in Table 19. Compared to the wastepaper programs, productivity of glass and metal programs is fairly poor. However, this is due to comparatively low participation in conjunction with relatively low generation rates for glass and metal in residential refuse.

Separate Truck Program Economics

The cost of a separate truck collection program and/or its impact on mixed refuse collection operations varies with a number of factors. Costs were assessed via two approaches:

- Fully allocated cost approach: separate collection costs are evaluated independently of mixed refuse collection and disposal costs. Costs were allocated for labor, equipment, etc., whether or not actually incurred.
- Incremental cost approach: incremental costs and/or savings accruing to a municipality when the overall costs of solid waste management are compared before and after implementation of a separate collection program. Costs included were only those actually incurred (i.e., if surplus trucks and/or labor were used, no out-of-pocket costs were incurred).

Fully Allocated Cost Approach. This approach assigns separate collection costs on an apportionment basis. For example,

TABLE 18

SEPARATE TRUCK PRODUCTIVITY FACTORS
-WASTEPAPER PROGRAMS-

Case Study Location	Separate Collection Trucks		Wastepaper Collected/mo (tons)	Ave. Tons Collected/ Truck/day
	No.	Truck-days/mo.		
1/mo Sep. coll'n frequency				
Briarcliff Manor, N.Y.	1	2	22	11.0
Great Neck, N.Y.	2	6	28	4.7
Green Bay, Wisc.	5	22	7	0.3
Marblehead, Mass.	2	10	46	4.6
Newton, Mass.	1	20	121	6.0
Average*,+				5.7
1/2 wk Sep. coll'n frequency				
Ft. Worth, Tex.	1	22	131	6.0
West Hartford, Conn.	2	44	220	5.0
Average*				5.3
1/wk Sep. coll'n frequency				
Cincinnati, Oh.#	6	130	167	1.3
Dallas, Tex.	9	39	145	3.7
Ft. Worth, Tex.	1	22	154	7.0
Greenbelt, Md.	1	9	32	3.6
Hempstead, N.Y.	6	130	813	6.2
University Park, Tex.	5	22	100	4.5
Average*,**				5.6

*Weighted by truck days per month.

+Does not include Green Bay due to extreme system idiosyncracies.

#Severe scavenger problem. Data accounts only for paper collected by municipality.

**Does not include Cincinnati due to scavenger problem.

TABLE 19

SEPARATE TRUCK PRODUCTIVITY FACTORS
-GLASS AND METAL PROGRAMS-

Material/Case Study Location	Separate Collection Trucks		Material Collected/Mo (tons)	Average Tons Collected/Truck/ Day
	No.	Truck-Days/Mo		
Glass				
Bowie, Md.	2	4	9	2.2
Green Bay, Wisc.	5	22	6	0.3
Marblehead, Mass.	2	20	32	1.6
Average*				1.7
Metal				
Bowie, Md.	2	4	3	0.8
Green Bay, Wisc.	5	22	3	0.1
Marblehead, Mass.	2	10	11	1.1
Average*				1.0

*Weighted by truck-days/per month. Does not include Green Bay due to extreme system idiosyncracies.

truck depreciation costs are assigned only for the portion of time that the truck is actually used for separate collection activity. Labor costs (including fringe benefits), truck operating costs (fuel, oil, tire repair and replacement, and maintenance parts and repair), and overhead expenses (administration, supervision, and facility costs) are similarly allocated. In this manner, costs are attributed on the basis of actual equipment and labor utilization whether one crew is required for a few hours per month or several are required on a daily basis.

Fully Allocated Separate Collection Costs. Figure 6 presents a profile of the separate truck case study locations depicting type of material separately collected, frequency of collection, the estimated fully allocated cost of the separate collection subsystem expressed on a per ton of material separately collected basis*, and relative size of the program based on the number of separate collection man-hours expended per month. Revenues from collected materials and saving in disposal costs are not included.

The plotted data reveal no apparent relationship between program size and the cost to perform separate truck collections. There are, however, other relationships worth mentioning. The collection cost variations between glass, metal, and paper are quite significant. Glass and metal were independently collected in Bowie, Green Bay, and Marblehead. Although the proportion of glass and metal in residential refuse is similar on a weight basis, glass collection costs were substantially lower, ranging from $76 to $81 per ton, as compared to metal collection costs of $115 to $202 per ton.[4,11]

The composition of the glass and metal components of household refuse is relative to separate collection and believed to account for much of this cost disparity. Glass, with the exception of occasional broken window panes or drinking glasses, is almost entirely comprised of one-way food and beverage containers. Metal composition in household refuse is different. Metal food and beverage containers, which comprise virtually all of the metal material separately collected are not as proportionately large in the "metal category" as are glass containers in the "glass category."

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*Where a separate collection program independently collected more than one type of recyclable material, applicable costs were assigned to the collection activities associated with that specific material using the fully allocated cost approach.

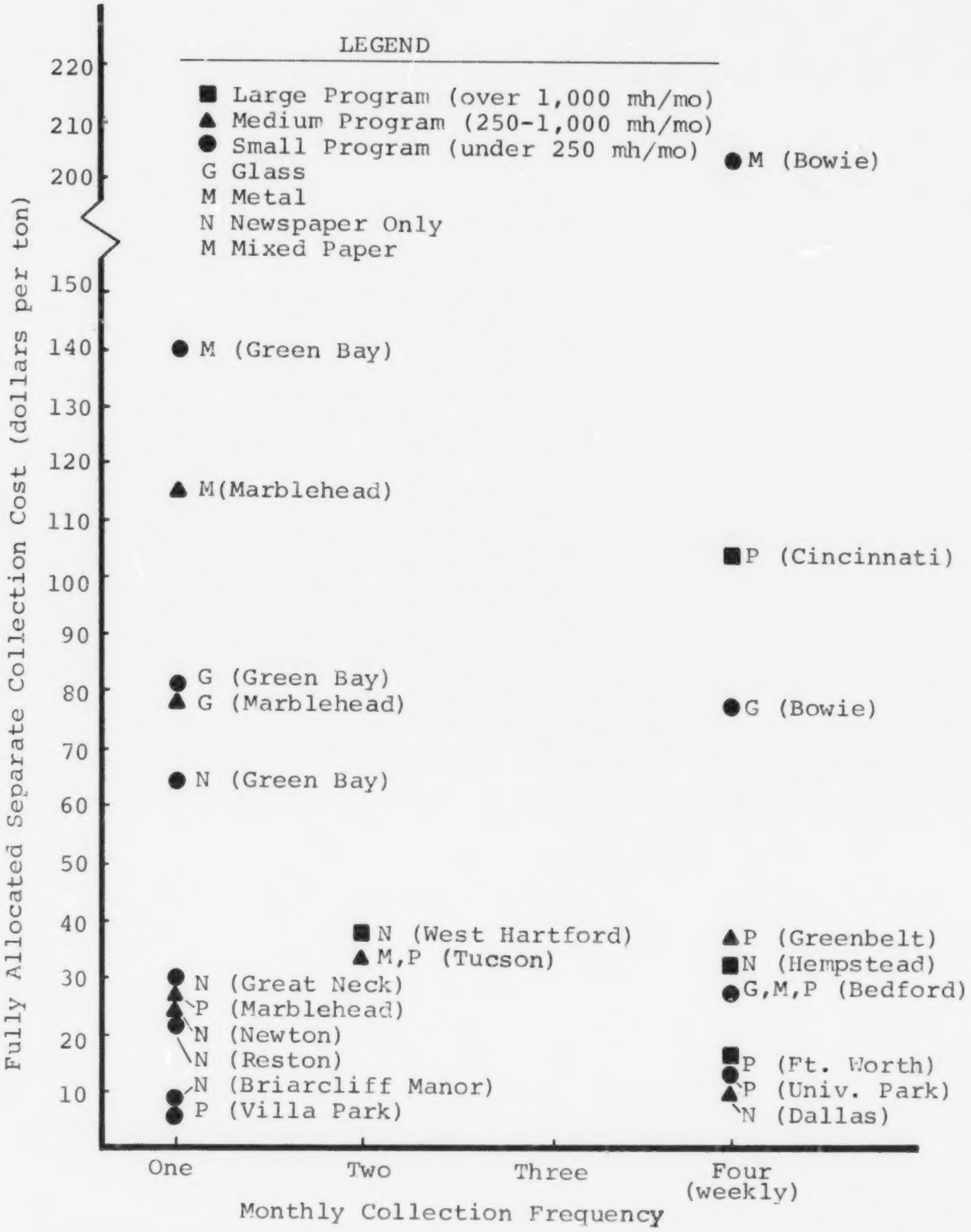

Figure 6 : Fully allocated cost profile of separate collection subsystems

Based on the household study, the ratio of recyclable glass generated per household per week (4.5 lbs) to that of metal (2.0 lbs) was 2.25 to 1. Although the study households were probably more conscientious in their separation efforts, similar ratios were evident in the glass/metal quantities collected at most of the case study locations:

Case Study Location	Quantities Collected (tons/mo) Glass	Metal	Ratio Glass/Metal
Bedford, Mass.	28	5	5.6:1
Bowie, Md.	9	3	3.0:1
Green Bay, Wis.	6	3	2.0:1
Marblehead, Mass.	32	11	2.9:1
Total/Average	75	22	3.4:1

In addition to glass components being readily separated by householders, a glass container weighs several times that of a metal container, thereby increasing weight placed for collection. The increased weight helped to lower unit costs of glass collection as compared to metal.

Two locations simultaneously collected more than one type of recyclable material - Bedford collected glass, metal, and mixed paper, and Tucson collected newspaper and metal at the same time. As shown in Figure 6, Bedford's collection cost was under $25 per ton and Tucson had a cost of about $32 per ton. In Bedford and Tucson, however, paper accounted for 50 and 80 percent of the total weight collected, respectively. The main drawback to large scale, simultaneous collection is the requirement to use an open truck and allocate space for each material.* In the case of Bedford, vehicle storage space allocated for paper always filled prior to the glass and metal storage space. This occurrence necessitated transfer trips to offload paper.

With two notable exceptions, independent wastepaper collection programs (newspaper only or mixed paper) had fully allocated separate collection costs below $40 per ton. Cincinnati had fully allocated collection costs of about $102 per ton.

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*Compactors are not presently compartmentalized. Maxon Industries, Inc., however, has designed a compartmentalized compactor. A 3 cu yd non-compacting compartment will soon be available to isolate recyclable materials from compacted mixed refuse.

As previously discussed, Cincinnati had a severe scavenger problem; thus collection productivity was reduced and costs increased. The Green Bay separate collection program was implemented by modifying an existing separate collection program. The existing program consisted of one truck used to collect combustibles and one for non-combustibles. The available non-combustible truck was reassigned to collect different recyclable materials on successive weeks in a pilot area. Although the system was relatively easy to implement, the collection capacity was too large to effectively collect the small quantities of recyclable material voluntarily separated in the pilot area. The high costs of the Green Bay operation reflect this condition.

The two programs with the lowest collection costs, Briarcliff Manor and Villa Park were both privately operated. In each location, an independent truck owner collected separated materials in exchange for the revenue received from material sales.* In Briarcliff Manor only newspapers were collected, while mixed paper was collected in Villa Park. Both programs were "one truck operations" whereby the driver and owner were one and the same and part-time labor was hired on an "as needed" basis. Thus, administrative and overhead costs for each program were negligible. This fact was reflected in the estimated fully allocated collection cost - $8 per ton at Briarcliff Manor and about $6 per ton at Villa Park.

Refuse collection operations are generally labor intensive and separate collection is no exception. Thus, labor costs are an important element in the overall cost of a separate collection program. In 1972 (latest data available), the U.S. Department of Labor tabulated the average first year salaries (exclusive of fringe benefits) of municipal refuse collectors in cities of 100,000 or more inhabitants on a regional basis as follows:[12]

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*Although not case study locations, the California cities of Fullerton and San Diego implemented private party programs whereby paperstock dealers provide respective separate collection services and pay the city for the "privilege" of making the separate collections. Fullerton is paid $5/ton for the first 100 tons of newspaper collected per month and $7/ton thereafter. A similar arrangement was agreed upon in San Diego. The city receives $5/ton for the first 500 tons/mo and $10/ton thereafter.

Region	Average Annual Salary per Collector
Northeast	$9,390
South	5,510
North-Central	8,700
West	7,780

Comparing the regional wage scales to the municipally operated programs in Figure 6 reveals a significant relationship. The three Texas programs (southern region) had the lowest collection costs while the northeast programs had the highest. Thus, at least a portion of the cost disparity between programs can likely be explained by regional labor cost differentials.

Effective Fully Allocated Separate Collection Costs. Separate collection costs are reduced by deducting revenue received for separated materials and diverted disposal savings.* Results are presented in Tables 20 and 21. Table 20 focuses on wastepaper programs only. Table 21 presents the data for glass, metal and multi-material programs (i.e., programs that separately collected more than one type of recyclable material).

As shown in Table 20, the impact of increased wastepaper revenues has had a significant impact on the program costs determined at the time of the case studies. April 1973 revenues and diverted disposal savings were insufficient to offset fully allocated separate collection costs in all municipal programs. The average loss was estimated to be almost $13 per ton of wastepaper collected. Confronted with this dismal financial picture, municipal separate collection program managers were generally unconcerned.# Most felt that the separate collection programs provided non-economic contributions which compensated for the "loss" as determined by the fully allocated cost method. Generally, the responses fell into three categories:

- Savings in landfill space and reduced incinerator loadings were worth the cost.
- Equipment and crews are better utilized.
- Citizens feel involved.

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*The methodology used to estimate diverted disposal savings is delineated in Appendix B.

#A copy of each case study was sent to the respective program managers for review and comment.

TABLE 20

EFFECTIVE FULLY ALLOCATED COSTS FOR SEPARATE TRUCK OPERATIONS -WASTEPAPER PROGRAMS-

Case study location	Fully allocated separate collection cost ($/ton)	Effective separate collection cost ($/ton)			
		Recyclable market at the time of case study (April 1973)		Current recyclable market (March 1974)	
		Revenue and diverted disposal savings	Net program savings (cost)	Revenue and diverted disposal savings	Net program savings (cost)
Municipal Programs					
Cincinnati, Oh.*	102.40	25.20	(77.20)	76.50	(25.90)
Dallas, Tex.	11.20	8.30	(2.90)	43.30	32.10
Ft. Worth, Tex.	17.40	10.10	(7.30)	35.90	18.50
Great Neck, N.Y.	29.70	15.70	(14.00)	19.00	(10.70)
Green Bay, Wisc.	63.50	18.80	(44.70)	38.80	(24.70)
Greenbelt, Md.	34.40	8.80	(25.60)	22.80	(11.60)
Hempstead, N.Y.	31.40	18.00	(13.40)	32.00	0.60
Marblehead, Mass.	27.50	6.40	(21.10)	33.40	5.90
Newton, Mass.	25.40	14.00	(11.40)	33.50	8.10
University Park, Tex.	12.00	8.70	(3.30)	43.70	31.10
West Hartford, Conn.	38.80	17.40	(21.40)	47.80	9.00
Average Municipal+			(12.70)		8.20
Private Party Programs#					
Briarcliff Manor, N.Y.	8.00	20.50	12.50	38.50	30.50
Reston, Va.	22.20	5.80	(16.40)	**	**
Villa Park, Ill.	6.20	10.60	4.40	38.60	32.40
Average Private			negligible		31.70

*Severe scavenger problem distorts program costs.
+Average does not include Cincinnati, Ohio.
#Bedford, Massachusetts and Tucson, Arizona collect wastepaper simultaneously with other recyclable materials; therefore not included with wastepaper only programs.
**Program abandoned.

TABLE 21

EFFECTIVE FULLY ALLOCATED COSTS FOR SEPARATE TRUCK OPERATIONS
-GLASS, METAL, MULTI-MATERIAL* PROGRAMS-

Case study location	Fully allocated separate collection cost ($/ton)	Effective separate collection cost ($/ton)			
		Recyclable market at the time of case study (April 1973)		Current recyclable market (March 1974)	
		Revenue and diverted disposal savings	Net program savings (cost)	Revenue and diverted disposal savings	Net program savings (cost)
Glass Programs					
Municipal Programs					
Bowie, Md.	76.60	22.00	(54.60)	No change	
Green Bay, Wisc.	80.50	28.80	(51.70)		
Marblehead, Mass.	79.00	11.40	(67.60)		
Average			(57.40)		
Metal Programs					
Municipal Programs					
Bowie, Md.	202.10	12.00	(190.10)	No change	
Green Bay, Wisc.	139.10	8.60	(125.30)		
Marblehead, Mass.	114.90	11.40	(103.50)		
Average			(122.60)		
Multi-Material Programs*					
Municipal Programs					
Bowie, Md.	108.00	18.70	(89.30)	18.70	(89.30)
Green Bay, Wisc.	85.00	17.00	(68.00)	22.00	(63.00)
Marblehead, Mass.	56.80	8.90	(47.90)	22.80	(34.00)
Average			(55.40)		(43.60)
Private Party Programs					
Bedford, Mass.	23.50	12.90	(10.60)	22.90	(0.60)
Tucson, Ariz.	32.70	7.30+	(25.40)	32.00+	(0.70)
Average			(14.00)		(0.60)

*Programs that separately collected more than one type of recyclable material. "Multi-material programs" collected different recyclable materials during successive weeks of the month (Green Bay and Marblehead); with different trucks on the same collection day (Bowie); or simultaneously with one truck (Bedford and Tucson).

+Does not include revenue from a $12 per year fee paid by householders for private separate collection service.

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Applying the March 1974 wastepaper revenue rates to the case study locations resulted in seven of the eleven municipalities showing a net profit for separate paper collection averaging about $8 per ton over all municipal programs (Table 20).

The private party paper programs fared better under depressed market prices. Two of the three private wastepaper programs had net gains although the overall private party average in April 1973 was about even. The one "losing program," Reston, folded prior to the March 1974 assessment. The two successful programs were more profitable as of March 1974, thus having an average net profit of about $32 per ton.

Glass and metal programs did not share the same degree of success experienced by wastepaper programs (see Table 21). There were no significant changes in glass and metal revenue rates between April 1973 and March 1974. Glass programs had average deficits of about $57/ton while the average metal program lost almost $123/ton. The relatively small quantities of glass or metal were not economically feasible for independent collection when the fully allocated cost approach is used.

The municipal multi-material programs shown in Table 21 represent a compilation of the costs of independently collecting the various types of materials. Each of the private parties simultaneously collected more than one material. With the exception of Bowie which collected glass and metal only, the multi-material programs benefited from the wastepaper price rise. Although operating at a significant deficit under the fully allocated cost approach, the municipal multi-material programs decreased the margin of loss from $55 to $44 per ton when March 1974 wastepaper prices were considered.

The private party multi-material programs rose from and average deficit of $14 per ton to a marginal loss of less than one dollar per ton.

Incremental Cost Approach. This approach assigns costs to the separate collection program only if the costs are incremental to costs budgeted for solid waste management. In determining whether a cost should be assigned under this approach, the user himself asks "will this cost be reflected as an increase in the budget for the next operating period?" If the answer is affirmative, the cost is assigned, otherwise it is ignored.

Thus, the incremental cost approach does not assign depreciation costs of available equipment to separate collection activities as it is not in excess of the established solid waste management budget. Similarly if trucks normally used for such functions as bulky collection (Bowie) or bursh collection (Dallas and University Park) were diverted for separate collection without adversely affecting the primary service, no incremental costs were attributed. However, the incremental operating costs for fuel, oil, tire/battery wear, and maintenance/repair due to the truck being activated or reassigned to separate collection would be incurred and are included. Additionally, if reserve labor was used for separate collection, there were no additional costs incurred in the solid waste management budget; thus no costs assigned. However, part-time hires, such as required in Marblehead and Newton would be incremental costs incurred by a separate collection program.

For the purposes of this analysis, equipment and labor diverted from municipal public works functions other than solid waste management were treated as incremental costs (e.g., highway department labor was used for separate collection in Great Neck)* and assigned. Overhead expenses for administration, supervision and facility requirements were unaltered although some additional record keeping was normally required.

Due to data limitations, analyses of overall collection and disposal costs before and after implementation of separate truck collection programs were possible at only 13 of the 17 case study locations as listed in Table 22. At the time of the case studies, 6 of the 13 programs had achieved a net reduction in collection and disposal costs due to separate collection and two others broke even. In terms of percent change due to separate collection activities, the net costs ranged from a reduction of about 5 percent to an increase of 7.5 percent, with an average increase of less than one percent for the 13 programs.

Substituting the respective March 1974 market values for separately collected materials into the case study analyses resulted in all but one of the 13 programs achieving a net reduction in residential solid waste management cost. Effective costs ranged from a decrease of 23 percent to an increase of one percent with an average decrease of about 7 percent. This significant reduction was entirely due to wastepaper price increases.

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*Case study locations using equipment and/or labor diverted from other public works functions were unable to quantify any adverse affect on the contributing functions. The incremental cost assumption was used as a proxy.

TABLE 22

IMPACT OF SEPARATE COLLECTION ON OVERALL
RESIDENTIAL SOLID WASTE MANAGEMENT COSTS
-SEPARATE TRUCK APPROACH-

Case study location	Collection and disposal cost prior to implementation of separate collection	Material separately collected*	Collection and disposal cost after implementation of separate collection+			
			Recyclable market at time of case study (April 1973)		Recyclable market (March 1974)	
	($/ton)		($/ton)	(% Change)	($/ton)	(% Change)
Bowie, Md.	18.10	G,M	18.10	0	18.10	0
Briarcliff Manor, N.Y.#	38.10	N	37.00	-2.9	36.30	-4.7
Cincinnati, Oh.**	29.20	P	29.20	0	28.50	- 2.4
Dallas, Tex.	12.10	N	11.50	-4.9	9.30	-23.1
Ft. Worth, Tex.	13.50	P	14.10	+4.4	11.80	-12.6
Great Neck, N.Y.	36.00	N	38.70	+7.5	36.50	+ 1.4
Green Bay, Wisc.	38.70	G,M,N	37.90	-2.1	37.40	- 3.3
Greenbelt, Md.	27.20	N	28.10	+3.3	27.10	- 0.4
Marblehead, Mass.	23.10	G,M,P	23.80	+2.9	22.60	- 2.2
Newton, Mass.	32.40	N	32.10	-0.9	31.50	- 2.8
University Park, #Tex.	14.70	P	14.30	-2.7	12.50	-15.0
Villa Park, Ill.#	13.50	P	13.40	-0.7	12.40	- 8.1
West Hartford, Conn.	26.30	N	26.60	+1.1	23.90	- 9.1

*G: Glass, M: Metal, N: Newspaper only, P: Mixed paper.

+Includes incremental costs of separate collection subsystem and credit for diverted disposal savings and revenue generated from sale of separately collected materials.

#Hypothetical cost of private party separate collection on overall residential solid waste management costs.

**Program costs distorted due to severe scavenger problem.

++Does not include Cincinnati due to scavenger problem.

Comparing the results of the incremental cost approach (Table 22) to those of the fully allocated cost approach (Tables 20 and 21) reveals some major differences. For example, fully allocated costs allocated to the Green Bay glass, metal, and newspaper program were quite high (about $81/ton for glass; $139/ton for metal; and $63/ton for newspaper). All amounts were in excess of revenue received and diverted disposal savings. However, using the incremental cost approach, this program achieved a 2 percent savings in the overall cost of solid waste management at the time of the case study. This increased to 3 percent when March 1974 revenue prices were considered.

Another example is provided by the Cincinnati program. Even though the scavenger problem decreased the effect of separate collection on overall solid waste management costs, Cincinnati was able to break even at the time of the case study and achieve a two percent reduction in overall costs when March 1974 revenues were considered.* This is an entirely different result when depicted by the fully allocated cost approach which estimated the loss in the Cincinnati program to be about $26 per ton of wastepaper collected.

Arguments of validity can be made for either the fully allocated or incremental cost approach, and the ultimate decision as to which approach is to be used must lie with the user.

The incremental cost approach was used by most case study municipalities in assessing the viability of their separate collection programs. As currently practiced, separate collection costs were generally absorbed within solid waste management budgets. However, as separate collection programs grow, the capability of a budget to absorb costs may be constrained by undue infringement on activities from which equipment and manpower has been borrowed. When, and if, this situation occurs, incremental resources will be required and incremental costs become fully allocated to separate collection.

Model Economics for the Separate Truck Approach

The case study costs are indicative of the economic viability of the case study programs as practiced. As previously noted, however, crew sizes were often excessive for collecting small quantities of separated materials. Also, case study locations had not re-routed mixed refuse collection vehicles to compensate for the reduced waste quantities diverted from disposal.

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*Cincinnati was receiving the highest wastepaer revenue of all programs at the time of the case study and in March 1974: $14.20/ton and $56.50/ton, respectively.

A refuse collection model[13] was adapted and exercised to evaluate further the economics of separate collection and its potential impact on overall collection costs. The resulting model evaluates costs of the separate collection subsystem, the impact of separate collection of mixed refuse collection (i.e., cost savings achieved via re-routing), and accounts for diverted disposal costs and revenue generated from sale of separately collected materials.

The model is fully described in Appendix C and was used to assess costs under the varying conditions shown in Table 23. Although the conditions and variables tabulated will likely not fit the exact conditions of any given municipality, the cost implications of a proposed separate truck subsystem may be assessed by plotting and/or reviewing appropriate "bracketing values" from the computerized printout accompanying this report and the examples developed in Appendix D. The accompanying tabulations account for variations in truck capacity; crew size; collection frequency; mixed refuse haul distance; the estimated collection cost prior to implementing a separate collection subsystem; and the effective cost of collection after implementation of the separate collection subsystem considering both revenue and diverted disposal savings.

If the conditions in a municipality are significantly different from those summarized in Table 23, the model may be used to obtain applicable results by inserting local variables and/or conditions. For example, only curb pickup of mixed refuse and separated newspaper was evaluated. Municipalities providing on-property service for mixed refuse should insert applicable information and exercise the model rather than attempt use of the tabulated data. Similarly, municipalities that estimate the average weight of newspaper per household to significantly exceed the 7 lbs per week used in the model would again be advised to exercise the model using applicable local conditions. The model is not extremely complex although time should be taken to obtain applicable data if the model is to be used. As a predictive tool, the model results will be as good as the input data.

TABLE 23

CONDITIONS ANALYZED VIA THE ADAPTED REFUSE COLLECTION MODEL

Variable	Mixed Collection	Separate Newspaper Collection
Crew Size (no./vehicle)	1-Side loader $\left.\begin{matrix}2\\3\end{matrix}\right\}$ Rear loader	1-Side loader $\left.\begin{matrix}2\\3\end{matrix}\right\}$ Rear loader
Collection frequency	1/wk, 2/wk	1/wk, 1/2wk, 1/mo
Collection location	curb	curb
Vehicle capacity (cu yd)	16,20,25 rear loader 20,25 side loader	12,16,20,25 rear loader 20,25 side loader
Generation rate (lbs/household/wk)	61*-1/wk coll'n 79+-2/wk coll'n	7 (newspaper only)
Labor cost	National average# $5.80-driver $4.70-loader	National average# $5.80-driver $4.70-loader
Haul distance	Short haul, long haul	Short haul
Disposal savings	----	Landfill and incineration (first and second party costs)
Revenue ($/ton)	----	8,25
Percent participation	----	20,50,80

*Based on 2.5 lbs per person per day and 3.5 persons per household.

+Based on research by Quon, generation rate increases with collection frequency.[14]

#Includes 25 percent fringe benefits.

Although being too extensive to delineate each of the more than 1,200 combinations resulting from the variables listed in Table 23, the printout accompanying the report can be used as a tool to provide insight to the potential impact of separate collection on overall solid waste collection costs. In order to exemplify the use and value of the model output, six collection situations were selected for inclusion in the report:

	Crew Size (no./vehicle)		Compactor Vehicle		Mixed Collection Frequency
Situation No.	Mixed	Separate	Type (loading location)	Size (cu.yd.)	(no./wk.)
1	3	3	Rear	20	1
2	3	2	Rear	20	1
3	1	1	Side	20	1
4	3	3	Rear	20	2
5	3	2	Rear	20	2
6	1	1	Side	20	2

The first and fourth situations were selected to typify the "average" municipal case study. These parameters included use of three man crews for both mixed and separate collection from the curb with 20 cu yd rear-loading compactors. Aside from changing mixed collection frequency, the only modification in the parameters of the second and fourth situations was reduction of separate collection crew size from three to two. The third and sixth situations represent minimization of crew size for both mixed and separate collection. For the purpose of illustration, mixed refuse collection frequency was fixed at either once or twice per week, while separate collection frequency was varied.

Results are shown in Figures 7 through 12. The dual set curves for each collection frequency represent differences due to long and short haul situations.* The tandem curves shown for long and short haul situations represent the difference in economic feasibility resulting from a change in revenue from an average of $8/ton to an updated market

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*Long and short haul situations were depicted in the model calculations by assuming respective one-way haul times of 15 min. and 45 min.

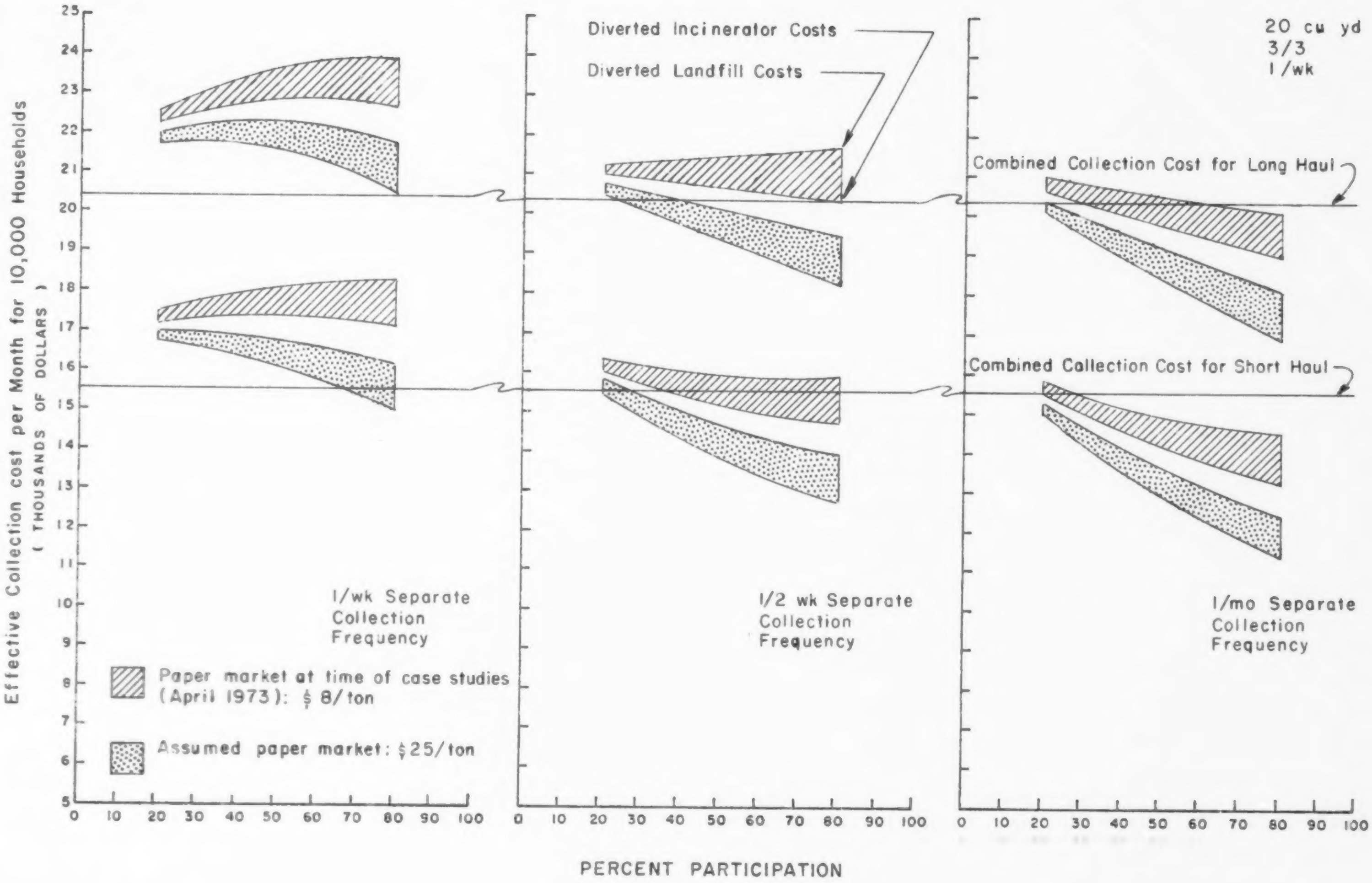

Figure 7. Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed once per week, 3 man separate collection crew.

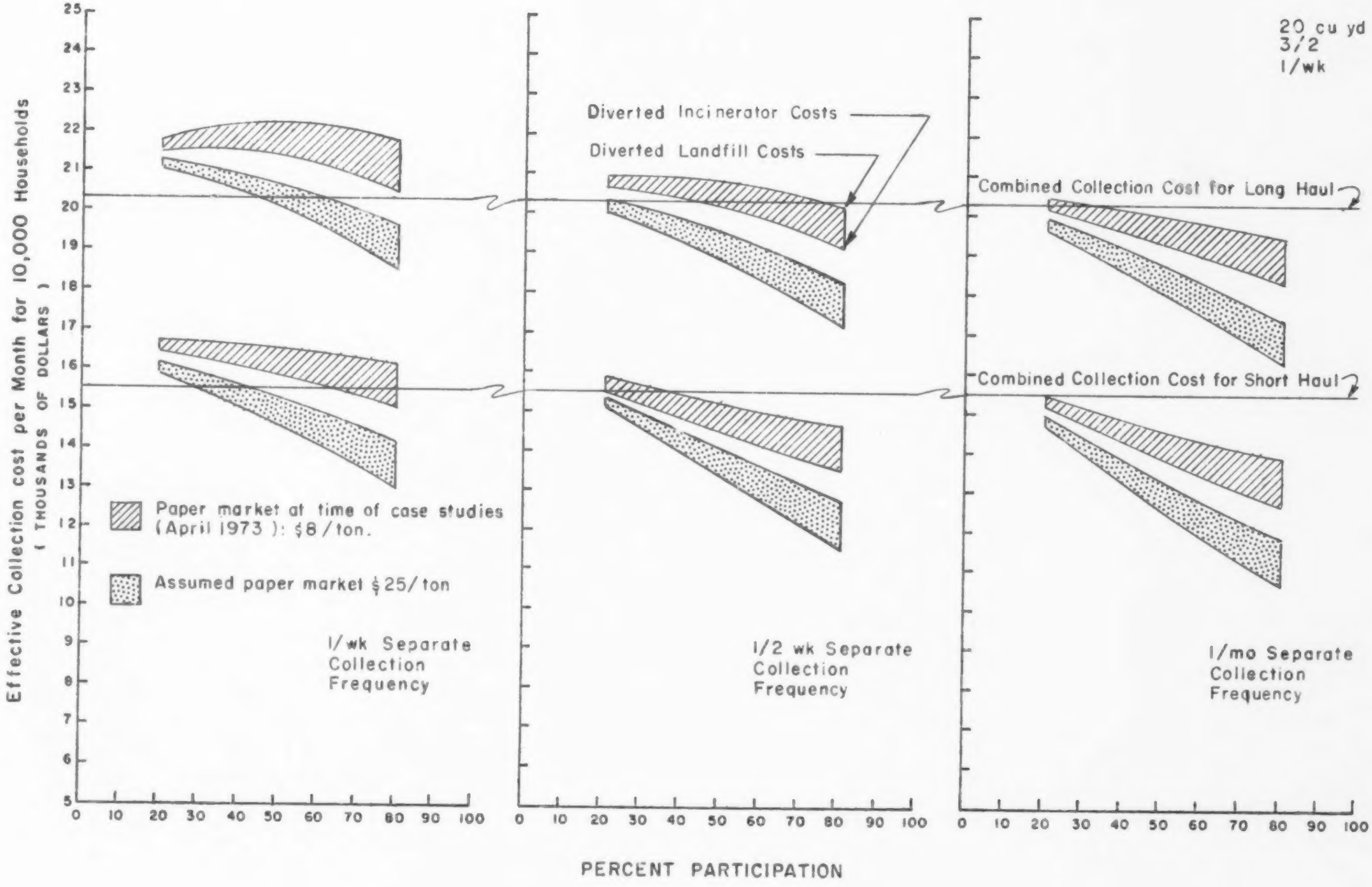

Figure 8 . Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed once per week, 2 man separate collection crew.

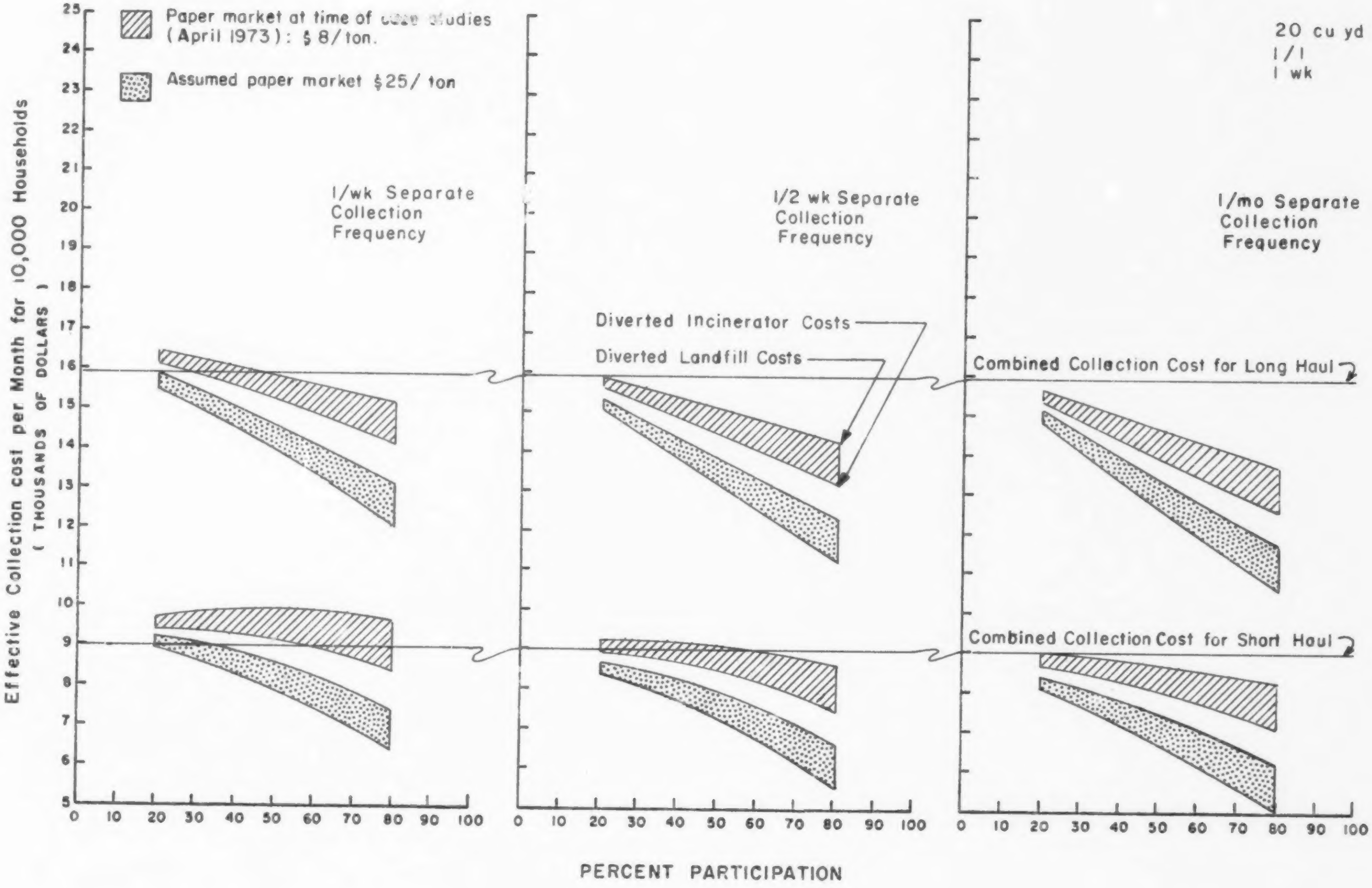

Figure 9 . Impact of optimizing refuse collection operations: exemplary analysis, 1 man mixed refuse collection performed once per week, 1 man separate collection crew.

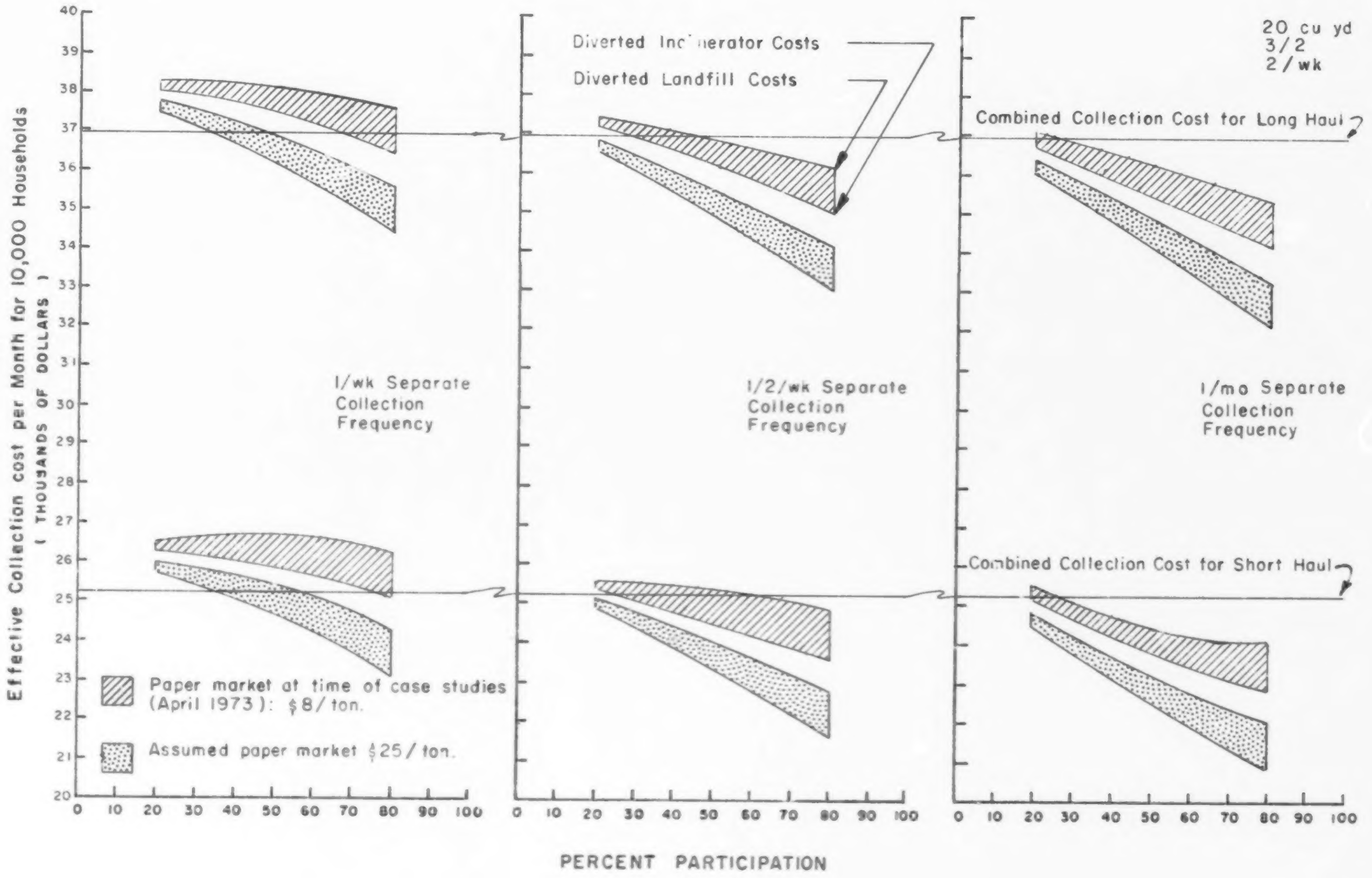

Figure 10. Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed twice per week, 3 man separate collection crew.

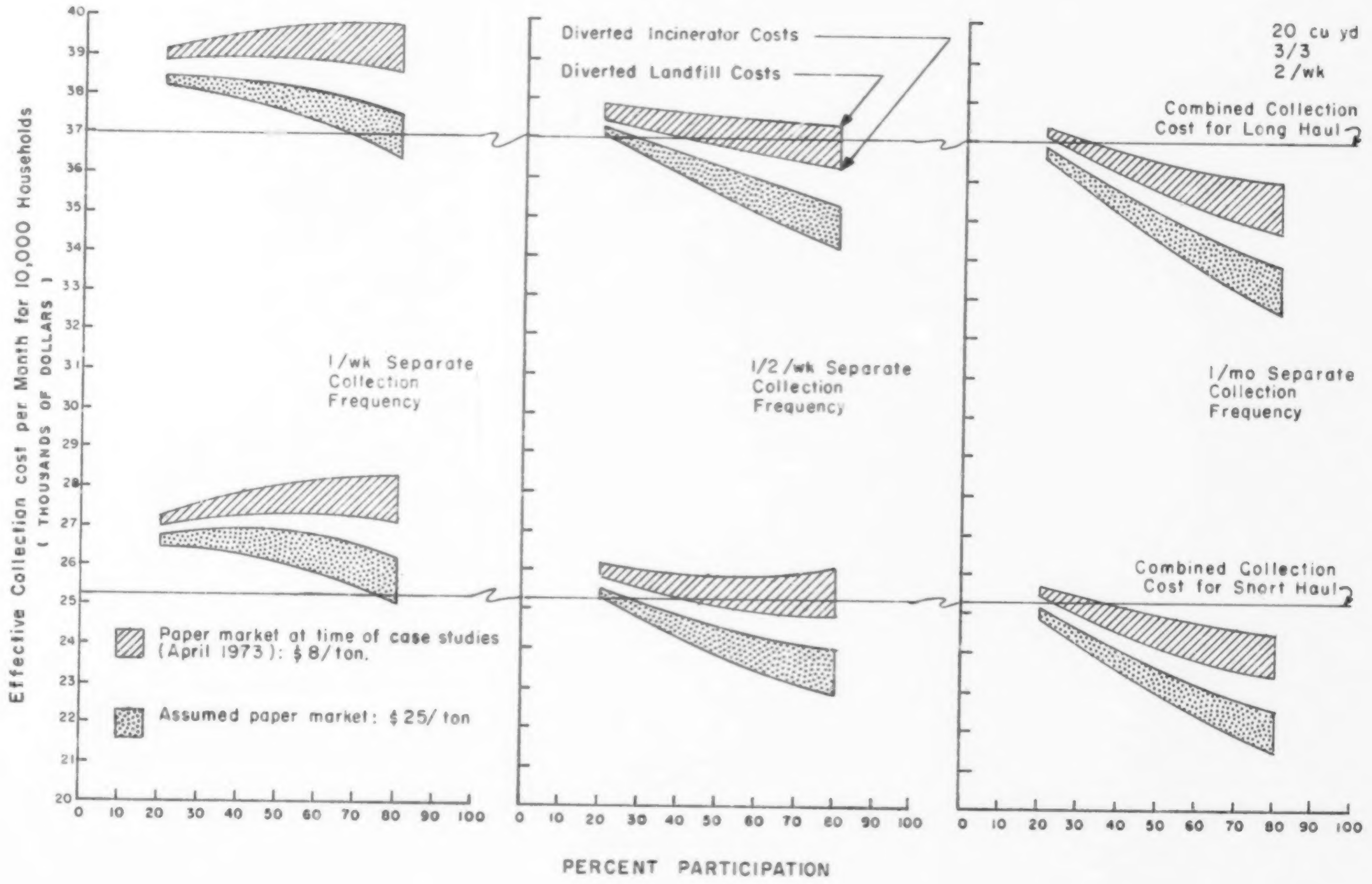

Figure 11. Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed twice per week, 2 man separate collection crew.

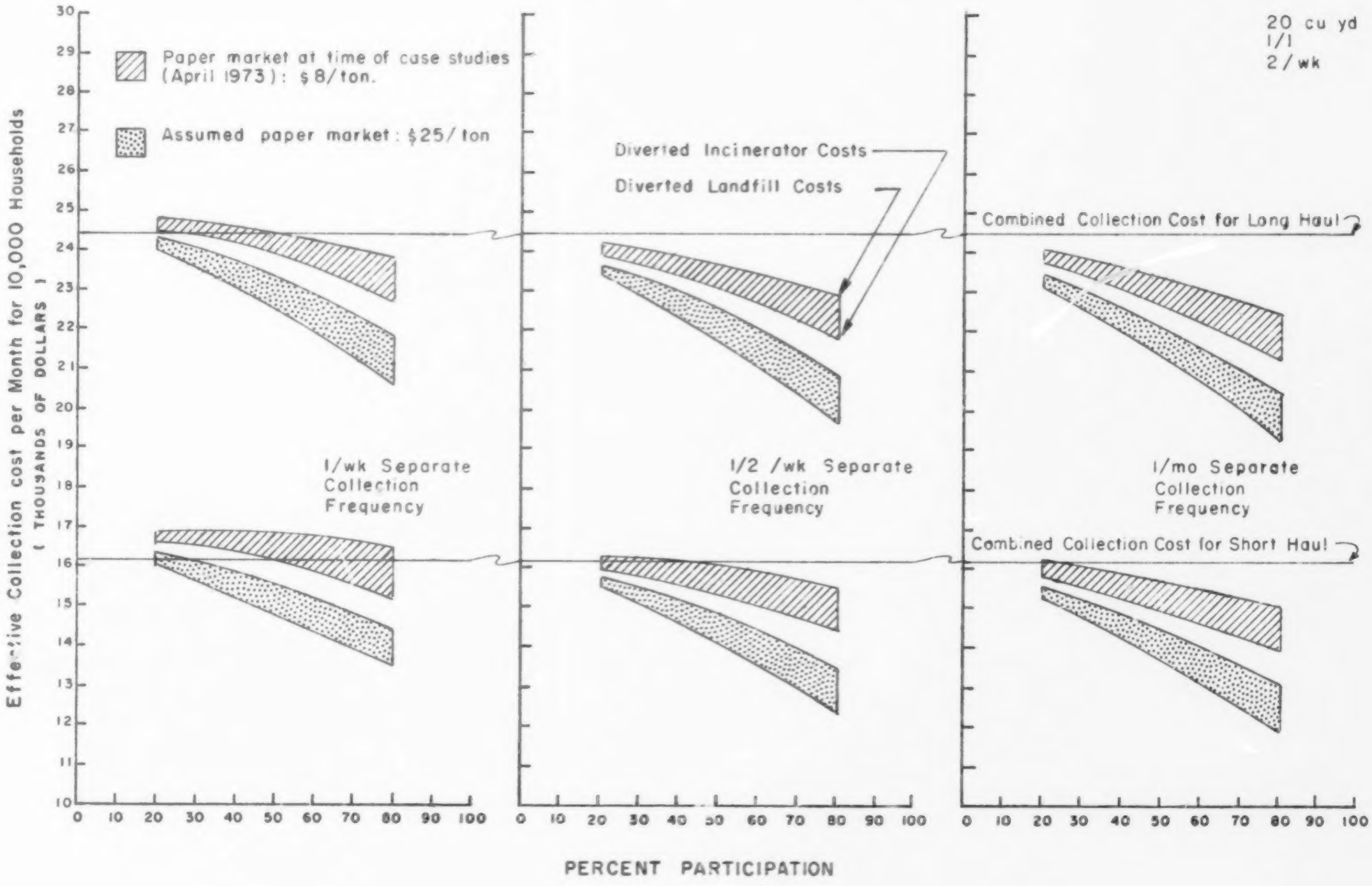

Figure 12. Impact of optimizing refuse collection operations: exemplary analysis, 1 man mixed refuse collection performed twice per week, 1 man separate collection crew.

price of $25/ton. The respective bands at each revenue rate represent the difference in diverted disposal cost savings between a city operating its own landfill to a city using a non-owned incinerator.

Separate collection is seen to have a more immediate impact in long-haul situations due to reductions in long-haul of mixed refuse. Similarly, savings attributed to quantities diverted from incineration have a higher payoff than quantities diverted from a landfill. Another logical consistency is that once per month separate collection in conjunction with mixed collection represents the least cost combination.

The variation in curve shape is due to the effect that revenue and disposal savings have on total collection costs at various separate collection frequencies. In essence, revenue and disposal savings have a dampening effect on overall collection costs. In certain instances these savings are not sufficient to dampen overall costs to a point where an effective cost decline results. Cost is the most sensitive to collection frequency and labor, and least sensitive to truck capacity (based on an assessment of all capacities listed in Table 23).

The importance of reducing separate collection crew size at the once per week separate collection frequency is shown by comparing Figures 7 and 8, or 10 and 11. Using the combined refuse collection cost (designated on the Figures) as a baseline situation, reduction of separate collection crew size from 3 to 2 results in a breakeven situation occurring with about 30 to 40 percent less participation at the 1/wk separate collection frequency. Reducing crew size at the 1/2wk and 1/mo separate collection frequencies resulted in breakeven situations occurring with 5 to 10 percent less participation. This apparent decline in impact is due to the relationship between quantity of newspaper per stop and crew size (i.e. at once per week, a crew collects 7 lbs per stop; at biweekly or monthly frequencies, the crew would respectively collect 14 or 30 lbs, inherently resulting in greater efficiency). Thus, economics of scale are evident.

The situations hypothesizing one man collection situations depict the least cost solutions for residential solid waste collection prior to and after separate collection implementation. The effect of lessening costs in almost every situation depicted in Figures 9 and 12 results from newspaper revenue and diverted disposal savings being able to overcome equipment and one-man labor costs at a faster rate than if two or three times the labor is used to collect identical quantities of waste (mixed or separate) when larger crews are used.

Regardless, the six illustrations typify the value of using the model in local decision making. Without a costly trial and error procedure, various service levels can easily be hypothesized, breakeven situations assessed, and savings and/or costs estimated.

VI

SEPARATE COLLECTION: RACK APPROACH

The most appealing aspect of the rack approach to separate collection is that mixed refuse and separated paper can be collected coincidentally by the same crew. With the rack system, paper bundles can be picked up with mixed refuse on regular residential collection days and placed in a separate rack attached to the collection truck. Figure 13 shows a typical rack configuration. Where residential collections were made simultaneously from both sides of the street, racks were attached to both sides of the truck.

Accordingly, refuse set-out habits of residents need not be altered. If curb service is provided, residents place bundled paper at the curb along with mixed refuse. Bundled paper was placed beside or on top of the mixed refuse container when on-property collection is provided. Therefore, the householder had the option of placing out bundled paper each collection day. A different schedule for separate collections need not be remembered.

Five rack programs were studied to obtain operational and cost information. Table 24 summarizes each case study location in terms of population, program initiation date, type of material collected and collection responsibility.

Total population of the case study cities ranged from about 50,000 in Sheboygan to the two largest cities in the nation-Chicago and New York. Population within the areas receiving rack service, however, was considerably less than the total in the two large cities: slightly under 10,000 in Chicago and about 60,000 in New York. The average number of residents per household within the five case study areas was about 3.3. The socio-economic status of the areas ranged from middle to between middle and upper-middle.

Two of the most enduring separate collection programs in the nation were among the five case studies. Sunset Scavenger Company, one of two private contractors in San Francisco, has separately collected residential refuse for over 25 years. When the firm converted their collection fleet to compactors in 1962, racks were added to isolate newspaper from mixed refuse. Madison implemented a rack program in 1968 with the cooperation of the American Paper Institute. The three other sites had all been in operation less than one year when studied.

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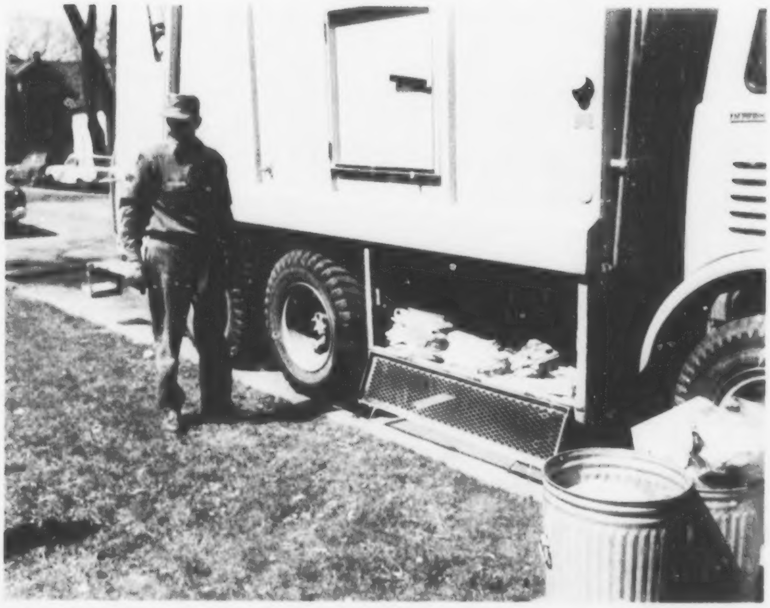

Figure 13. Rack configuration used in Madison, Wisconsin for separate collection of newspaper.

TABLE 24

RACK COLLECTION PROGRAM BACKGROUND

Case study location	Population (thousands)*		Program initiation date	Materials separately collected		Collection responsibility	
	Total	Served by sep. coll'n.		Newspaper	Other paper	Municipal	Private
Chicago, Ill.	3,600	10[+]	May 1972	X		V***	
Madison, Wisc.	170	170	Sept. 1968	X		V	
New York, N.Y.	7,800	60[#]	Oct. 1972	X		V	
San Francisco, Calif.	720	430**	1962[++]	X			V
Sheboygan, Wisc.	50	50	June 1972	X	X[##]	V	

*Rounded to nearest 10,000.

+Nineteenth ward only.

#Queens Sanitation District 67 only. Several other sanitation districts receive rack service but not studied due to lack of data.

**Residential accounts serviced by Sunset Scavenger Company only; about 60 percent of San Francisco residents. Remaining residents receive rack service from another private contractor.

++Sunset Scavenger Company has separated residential refuse for over 25 years. Racks installed on compactor trucks for separate newspaper collection in 1962.

##Magazines.

***V: Voluntary household separation.

The only rack case study site to separately collect material other than newspaper was Sheboygan. Bundled magazines were collected concurrently with newspaper, although quantities were so small that data were not kept by program officials. Thus, the ensuing analysis will focus on newspaper collection only.

Four of the five programs were operated by municipalities, and one (San Francisco) was operated by a private contractor. As opposed to the small private party separate truck programs studied, San Francisco receives separate collection service from a large private contractor.

Each rack program operated on the basis of voluntary household participation. There were no known mandatory rack programs in existence when the case study sites were selected.

Rack Activities

Activities associated with the rack approach to separate collection are shown in Figure 14 . As might be expected, the rack approach requires an incremental amount of collection time at each stop when paper is separately bundled and placed with mixed refuse for collection. However, none of the case study sites were able to quantify the incremental loading time. A time study was conducted in San Francisco.[15] The incremental time required per collection stop for rack collection of bundled newspapers was determined to average 14 seconds.

There were also incremental rack unloading times to be considered when evaluating feasibility of the rack approach. Where an appreciable participation rate was attained, racks often filled with newspaper prior to the truck filling with refuse. Transfer operations to cope with this situation were observed in Madison and San Francisco:

- In Madison, the racks filled one to two times before the trucks filled with mixed refuse. Each day lugger boxes and/or dump trucks are prepositioned in the collection areas for rack unloading. Even with prepositioning, each truck spent about 15 minutes off-route per truck load (driving time and rack unloading time).

- In San Francisco, there were only a few heavy newspaper generating routes. To circumvent the problem of trucks leaving the route, full racks are off-loaded at prearranged locations. A separate truck was employed to gather and deliver the bundles to the

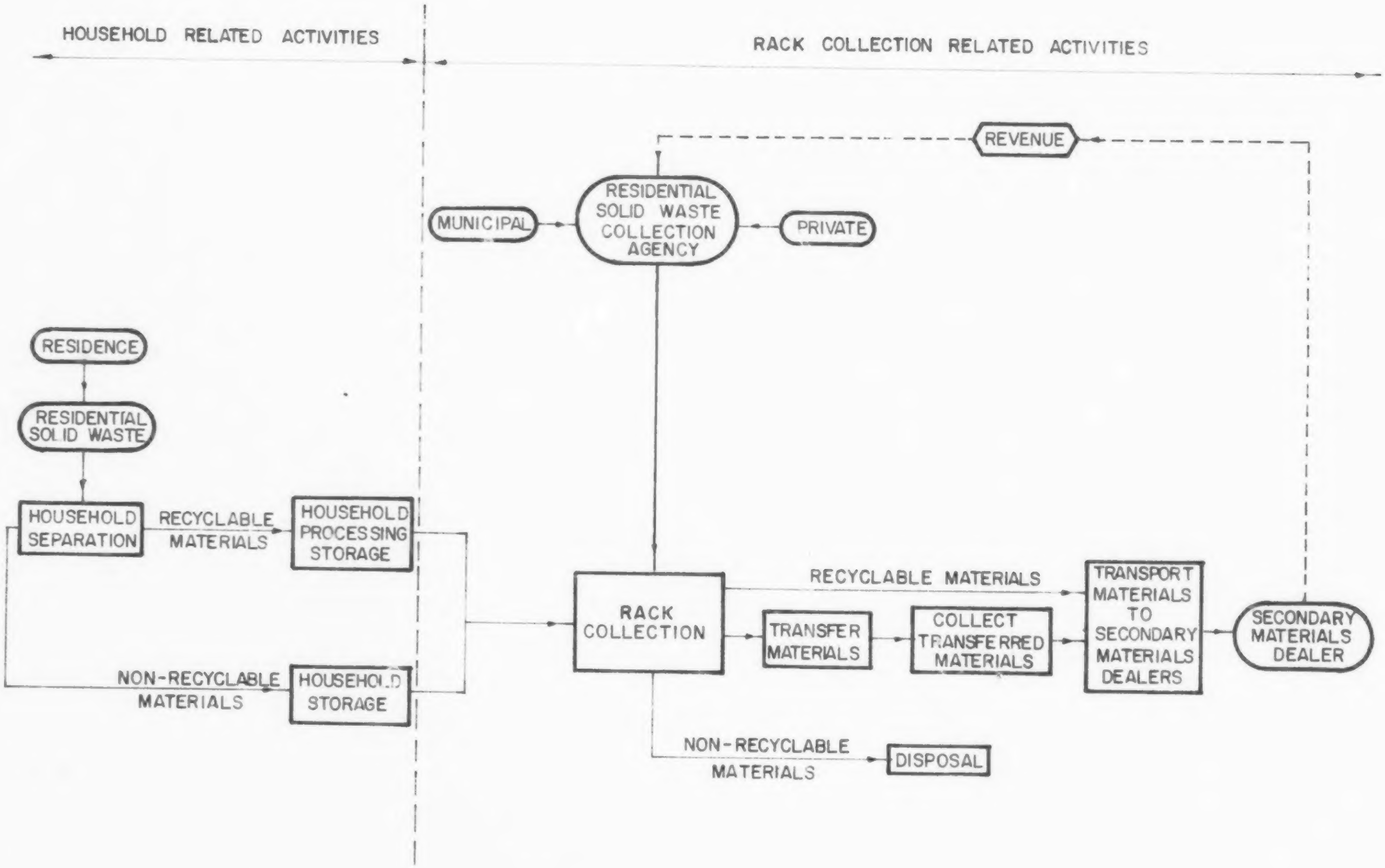
HOUSEHOLD RELATED ACTIVITIES
RACK COLLECTION RELATED ACTIVITIES
REVENUE
MUNICIPAL
RESIDENTIAL SOLID WASTE COLLECTION AGENCY
PRIVATE
RESIDENCE
RESIDENTIAL SOLID WASTE
HOUSEHOLD SEPARATION
RECYCLABLE MATERIALS
HOUSEHOLD PROCESSING STORAGE
NON-RECYCLABLE MATERIALS
HOUSEHOLD STORAGE
RACK COLLECTION
RECYCLABLE MATERIALS
TRANSFER MATERIALS
COLLECT TRANSFERRED MATERIALS
TRANSPORT MATERIALS TO SECONDARY MATERIALS DEALERS
SECONDARY MATERIALS DEALER
NON-RECYCLABLE MATERIALS
DISPOSAL

Figure 14 : Rack related collection activities.

secondary materials dealer. About 5 minutes were required to offload contents of the two racks.

Sheboygan circumvented the transfer problem completely by discarding excess bundled paper into the truck with the mixed refuse after the rack filled. The New York program was not confronted with transfer operations due to a very low participation, nor was Chicago due to severe scavenger problems.

When the truck fills with mixed refuse (or the end of the collection day arrives), the newspaper bundles were offloaded into a van or storage bin. With the exception of New York, interim storage containers were provided and collected by a paperstock dealer. New York placed a city-owned lugger box at the disposal facility and subsequently provided transportation of containers and contents to the paperstock dealer. At all locations, interim storage containers were placed adjacent to the disposal facility to minimize time lost due to rack offloading. Offloading times required from 2 to 5 minutes per truck. None of the case study locations performed any degree of newspaper processing after collection.

Startup Costs

Startup costs associated with rack programs were low. As discussed in Section V, initial publicity costs averaged 15 cents per residence served. There were no reported incremental labor costs associated with the rack programs. Initial equipment costs were limited to fabrication and installation of the rack(s).

Rack capacities ranged from a low of 0.5 cu yd in New York to a high of 1.25 cu yd in San Francisco. The most patterned after rack configuration was developed for use in Madison and has a capacity of about 1 cu yd (refer to Figure 13). Both Chicago and Sheboygan adopted the Madison configuration. Reported costs for fabrication and installation are shown in Table 25 and ranged from a low of $80 per rack in Sheboygan to a high of $250 each in San Francisco.

Based on a five-year straight line depreciation in conjunction with the average quantities of newspaper separately collected, the amortized cost of racks ranged from $0.40 per ton in Madison to $5.60 per ton in New York. The average amortized cost of racks was about one dollar per ton for all programs.

TABLE 25

AMORTIZED STARTUP COSTS
-RACK APPROACH-

Case study location	Startup cost/truck			Average tons collected per truck/mo	Amortized cost* ($/ton)
	Cost/rack	Racks/truck	Total		
Chicago, Ill.	$ 100	1	$ 100	*	*
Madison, Wisc.	170	1	170	7.6	0.40
New York, N.Y.	100	2	200	0.6	5.60
San Francisco, Calif.	250	2	500	6.2	1.30
Sheboygan, Wisc.	80	1	80	1.9	0.70
Average				5.5	1.10

*Chicago, Ill. data not included due to severe scavenger problem.
+Based on 5 year straight line depreciation; rounded to nearest $0.10.

Equipment and Manpower Utilization

Table 26 summarizes truck and crew sizes used at the case study locations. All the rack case study locations used rear loading compactor vehicles with capacities ranging from 16 to 25 cu yd. Crew sizes remained the same as before implementation of separate collection -- an average of 2.8 crewmen per truck.

Rack Program Performance

Rack program performance was assessed in terms of participation achieved, waste quantities diverted from disposal, and collection productivity.

Participation. Table 27 presents performance profiles for the rack system case study locations. Madison had achieved the highest participation - about 40 percent. Based on a four year average, participation in the residential sectors of San Francisco serviced by Sunset Scavenger Company was 18 percent. The Sheboygan and New York programs received the lowest participation rate - 10 and 2 percent, respectively.* The average participation rate for all rack programs, 21 percent, should not be construed as typifying the rack approach due to considerations discussed in the following paragraphs.#

With no variation in mixed versus separate collection frequency or schedule, public relations/education would appear to be the necessary ingredient to entice greater participation in the rack programs studied. Of the case studies, Madison provided the most program publicity through continuous reports of program progress, landfill savings, etc. Sunset Scavenger Company in San Francisco embarked on a major publicity campaign to recycle newspaper in conjunction with Earth Day 1970. Participation for the following six months varied from 30 to 40 percent. The resulting quanti-

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*Although not shown in Table 27, a survey of scavengers by Chicago officials indicated that householder participation was as high as 75 percent in the pilot area at program onset. On-going participation waned, however, when householders learned or observed that the separated paper was not being collected by city forces.

#Due to the small number of rack programs studied, generalities are often difficult to derive because uncontrolled program idiosyncrasies or variables can have significant impact on averages drawn from small samples. Thus, the merits or drawbacks of individual programs will be drawn upon throughout this section.

TABLE 26

EQUIPMENT AND MANPOWER UTILIZATION:RACK OPERATIONS

Case Study Location	Collection vehicles (no.)*	Vehicle sizes (cu yd)	Normal crew size (men)
Chicago, Ill.+	3	20,25	3,4
Madison, Wisc.	32	16,20	2
New York, N.Y.#	18	20	3
San Francisco, Calif.	78	20,25	3
Sheboygan, Wisc.	10	16	3
Average		20.7	2.8

*All were compactor types; number used in separate collection area only.
+Nineteenth Ward only.
#Queens Sanitation District 67 only.

TABLE 27

PERFORMANCE PROFILES FOR RACK SYSTEM CASE STUDY LOCATIONS

Case Study Location*	Participation Rate	Average Quantities Collected		Disposal Reduction
		Total Residential Refuse	Separated Newspaper	
	(%)	(tons/mo)	(tons/mo)	(% by Weight)
Madison, Wisc.	40	4,250	242	5.7
New York City, N.Y.[+]	2	4,360	11	0.2
San Francisco, Calif.[#]	18	13,170	482	3.7
Sheboygan, Wisc.**	10	1,530	19	1.2
Total/Average	21	23,310	254	3.2

*Chicago, Ill. not included due to a severe scavenger problem distorting the program profile.

+Queens District 67 only.

#Residential accounts serviced by Sunset Scavenger Co. only (about 60 percent of San Francisco residents).

**Newspaper only. Data not available on quantities of magazines separately collected.

ties collected exceeded market demand, and the firm was forced to curtail collection. At the time of the case study, and in conjunction with a rising wastepaper market, the firm was again in the process of requesting more newspaper.

The San Francisco problem illustrates the importance of knowing market capabilities for absorbing incremental quantities of recyclable materials. Householders cannot be motivated and demotivated at the qualms of the market without losing interest in participation.

Little publicity was provided in the Sheboygan and New York case study locations. Although the respective program officials acknowledged the need for householder motivation, these two programs were allowed to seek their own level of participation. It should also be noted that both programs were in middle class communities which generally achieved the lowest participation rates of all separate collection programs studied - rack and separate truck.

Diverted Disposal. As shown in Table 27, only Madison and San Francisco had significant diversion rates (about 6 and 4 percent, respectively). The same rationale provided for participation holds true for explaining the low diversion rates for Sheboygan and New York - i.e., no stimulation through public relations, etc. Of positive note, however, is the fact that the Madison program provides evidence that the rack approach has the potential to divert significant waste quantities from disposal.

Collection Productivity. Productivity of the rack approach was measured in terms of tons of newspaper collected per truck per month. Referring to Table 25, productivity ranged from less than 1 to about 8 tons per truck per month in the case study locations. The Madison and San Francisco programs again provide an indication of productivity potential with respective monthly rates of about 8 and 6 tons per truck.

Program Economics

The cost of a rack program and/or its impact on overall residential refuse collection costs is dependent on several factors: size of the rack(s) used, participation rate which, if appreciable, necessitates an on-route transfer operation, whether transportation of accumulated newspaper is provided by the collector or the paperstock dealer, revenue received from newspaper sales, and savings attributed to diverted disposal. Without repeating the rationale discussed in the economic analysis of the separate truck approach, both the fully allocated and incremental cost approaches to evaluating the economics of the rack approach will be presented.

Fully Allocated Cost Approach. Aside from rack costs, the rack method for separate collection was not as amenable to analysis by the fully allocated cost approach as was the separate truck method. The separate truck method entailed two distinct operations: mixed refuse collection and separate collection of recyclables. The rack approach entails one operation entailing two functions. Because of inherent complexities, the operation is difficult to analyze by the fully allocated cost method.

For example, crew sizes, number of trucks, and route lengths at all case study locations remained unaltered after rack system implementation regardless of the fact that incremental crew time was required for rack loading, transfer operations, and rack unloading. This implies that the overall efficiency of refuse collection was improved by utilizing "fat" in mixed refuse collection operations to absorb the incremental time requirements. The effectiveness of the rack approach, therefore, is keyed to the ability of the mixed refuse collection system to absorb the incremental time requirements. Further generalization of the preceding statement via fully allocated costs or averages would be meaningless as efficiency of municipal and private operations will vary considerably from city to city.

The fully allocated cost approach can, however, be aptly applied to special requirements generated by the rack method. For example, Madison and San Francisco interim newspaper transfer operations were necessitated by separated newspaper quantities exceeding rack capacity prior to mixed refuse filling the truck. Similarly, New York opted to deliver collected newspaper to the paperstock dealer in favor of higher revenue versus a lower revenue if a reciprocal agreement had been made.

The Madison transfer technique, as previously described, consisted of daily positioning of lugger boxes and/or dump trucks in collection areas. Positioning and retrieving these transfer containers required an average of four manhours of labor per day. Equipment requirements consisted of two dump trucks, two lugger boxes, and a hoist truck to transport the lugger boxes. Including applicable fringe benefits and administrative overhead costs, the fully allocated cost of the Madison transfer operations amounted to $4.80 per ton of newspaper collected.

San Francisco employed an "on-route" transfer operation and an "off-route" offloading operation. The on-route transfer operation, as outlined earlier, consisted of emptying full racks at prearranged locations whereupon a second truck (20 cu yd rear-loading compactor) with a one man crew reloaded the newspaper bundles and delivered them to the paperstock dealer. This transfer technique was conducted on a full time basis - 5 days per week, 8 hrs per day. Although the truck and driver were both from reserve forces, the fully allocated cost of the newspaper transfer operations was about $11.50 per ton.

The offloading operation was conducted at the approach to the refuse transfer station. Two laborers were employed to offload newspaper from the side racks, break the bundles, check for contaminating materials, and re-load the newspaper into a truck provided by the paperstock dealer. Each laborer spent five hours per day offloading paper which equated to a fully allocated cost of $1.60 per ton of newspaper collected. Together, the transfer and offloading operation amounted to an estimated fully allocated cost of $13.10 per ton in San Francisco.

New York was the only case study location to transport collected newspaper directly to the paperstock dealer. Transporting the paper, which was stored in a 12 cu yd lugger box, required one man and a hoist truck. During a six month period an average of seven trips monthly had been made to the paperstock dealer. The fully allocated cost of transport amounted to $28.10 per ton of newspaper.

With respect the the preceding transfer and transport costs, and the amortized rack costs estimated in the startup cost discussion, Table 28 presents the fully allocated costs associated with the rack operations studied. Also shown is the revenue received at the time of case study and in March 1974, and savings attributed to diverted disposal. Two of the four programs, Madison and Sheboygan, achieved a net savings while New York and San Francisco operations showed a net loss under the fully allocated approach.

The fully allocated cost analysis approach is most applicable to a collector with limited resources (equipment and labor). Madison, New York, and San Francisco were able to use reserve equipment and labor such that the "out-of-pocket" costs were substantially less than the fully allocated costs depicted in this assessment. For a collector not able to utilize reserve forces, the fully allocated costs provide insight into rack system economics.

TABLE 28

ESTIMATED FULLY ALLOCATED COST AND SAVINGS
-RACK OPERATIONS-

Case study location*	Fully allocated collection costs ($/ton)		Revenue and savings ($/ton)			Net savings (cost) of rack operations# ($/ton)	
			Newspaper revenue				
	Rack amortization	Newspaper handling+	At time of case study (April 1973)	Updated newspaper market (March 1974)	Diverted disposal savings	At time of case study (April 1973)	Updated newspaper market (March 1974)
Madison, Wisc.	0.40	4.60	6.80	32.00	1.40	3.20	28.40
New York, N.Y.**	5.60	28.10	10.00	16.50	6.40	(17.30)	(10.80)
San Francisco, Calif.++	1.30	13.10	3.00	3.00##	6.60	(4.80)	(4.80)
Sheboygan, Wisc.	0.70	0	10.00	20.00	5.60	14.90	24.90

*Chicago, Ill. not included due to a severe scavenger problem distorting the program results.
+Newspaper transfer or delivery of newspaper to paperstock dealer after interim storage.
#Represents the savings or costs of collecting separated paper.
**Queens Sanitation District 67 only.
++Residential accounts serviced by Sunset Scavenger Company only (about 60 percent of San Francisco residents).
##Due to a corporate relationship between Sunset Scavenger Company and the paperstock dealer, there was no change in the newspaper revenue between April 1973 and March 1974.

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Incremental Cost Approach. The incremental cost approach assigns costs to the rack system only if incremental to solid waste management costs prior to system implementation. For example, rack amortization costs were incremental in each location; however, transfer operations were performed in Madison and San Francisco using budgeted equipment and labor. Thus, in the latter two locations, only equipment operating and maintenance costs are incremental, not equipment depreciation or labor costs. The same rationale is applicable to transporting newspaper to the paperstock dealer in New York.

On the other hand, the labor costs to offload newspaper at the approach to the refuse disposal facility in San Francisco were incremental. It is in this manner that operators providing mixed collection service viewed their costs of implementing the rack system.

Using the incremental cost approach in conjunction with revenue and disposal savings, overall collection and disposal costs before and after implementation of the rack systems were calculated and are shown in Table 29. As seen, each rack program achieved a small net reduction of overall solid waste management costs at the time of case study and an average reduction of about one and a half percent when March 1974 revenue rates were considered. Madison was able to effectively reduce costs by over seven percent. Due to a corporate relationship between Sunset Scavenger Company and the paperstock dealer, the rate of newspaper revenue ($3/per ton) was low and remained unchanged at the time of case study and in March 1974. Substituting the average March 1974 wastepaper revenue of $31/ton received by all case study locations (separate truck and rack, exclusive of San Francisco) resulted in potential net reduction of over two percent in solid waste management costs in San Francisco.

Although the Sheboygan and New York programs had low participation rates, they were nonetheless able to attain marginal overall cost reduction.

Again, the incremental cost approach should be used by a municipality to bring costs into proper perspective. Fully allocated costs are valuable, however, to independently assess the effectiveness of peripheral operations induced by a rack system.

TABLE 29

IMPACT OF SEPARATE COLLECTION ON OVERALL RESIDENTIAL SOLID WASTE MANAGEMENT COSTS -RACK APPROACH-

Case Study Location*	Collection and Disposal Cost Prior to Implementation of Separate Collection	Collection and Disposal Cost After Implementation of Separate Collection			
		Wastepaper Market at the Time of the Case Study (April 1973)		Current Wastepaper Market (March 1974)	
	($/ton)	($/ton)	(% Change)	($/ton)	(% Change)
Madison, Wisc.	22.30	22.00	-1.3	20.70	-7.2
New York, N.Y.+	53.50	53.40	-0.2	53.40	-0.2
San Francisco, Calif.#	30.50	30.40**	-0.3	30.40**	-0.3
Sheboygan, Wisc.	32.00	31.80	-0.6	31.70	-0.9

*Chicago, Ill., not included due to a severe scavenger problem distorting the program results.

+Queens District 67 only.

#Residential accounts serviced by Sunset Scavenger Company only (about 60 percent of San Francisco residents).

**No change was made in the newspaper revenue rate received between April 1973 and March 1974 (see text).

Model Economics for the Rack Approach

The effectiveness of the rack approach to separate collection depends on the ability of the mixed collection system to absorb the incremental time requirements for paper collection and transfer. Due to the many variations between refuse collection systems, it is difficult to describe and evaluate an average case for capability to absorb incremental time requirements. However, by using the Madison rack collection procedures* as exemplary, a hypothetical municipality of 10,000 households was evaluated via the adapted collection model (Appendix E) to illustrate the effect of instituting rack operations on an efficient collection system where no additional collection time requirements could be absorbed without additional equipment and labor. The results of the analyses are presented in Figures 15 and 16 depicting short and long disposal haul situations, respectively. Each figure shows the effective collection costs per month after implementation of rack operations for the hypothetical municipality reflecting revenue rates of $8 per ton and $25 per ton and the extremes of possible disposal cost savings (i.e., first party landfill to second party incinerator). Also plotted for comparative purposes is the estimated baseline cost for mixed refuse collection prior to implementation of rack operations (designated "combined refuse collection cost").

The discontinuities shown in the short haul situations (Figure 15) delineate points (35 and 70 percent participation) where off-route transfer of newspaper is required. At these points, a quantum increase in cost is incurred by a collection system unable to absorb incremental time requirements. The relationship reflecting revenue at $8 per ton shows savings exceeding collection cost only under the circumstances of less than 35 percent participation (no transfer operations required) and second party incinerator disposal savings.

The economic projections with revenue at $25/ton are more favorable. Incremental costs are more than covered by savings when participation is less than 35 percent. Although not as substantial, costs were almost always covered between 35 and 70 percent while only savings attributed to diverted

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*Madison used 20 cu yd rear-loading compactors for mixed collection, each equipped with a one cu yd rack to isolate separated newspaper bundles. Labor consisted of a driver and a loader (i.e., 2 man crew), and mixed/separate collection was made once per wk. The "on-route" transfer system consisted of prepositioned lugger boxes.

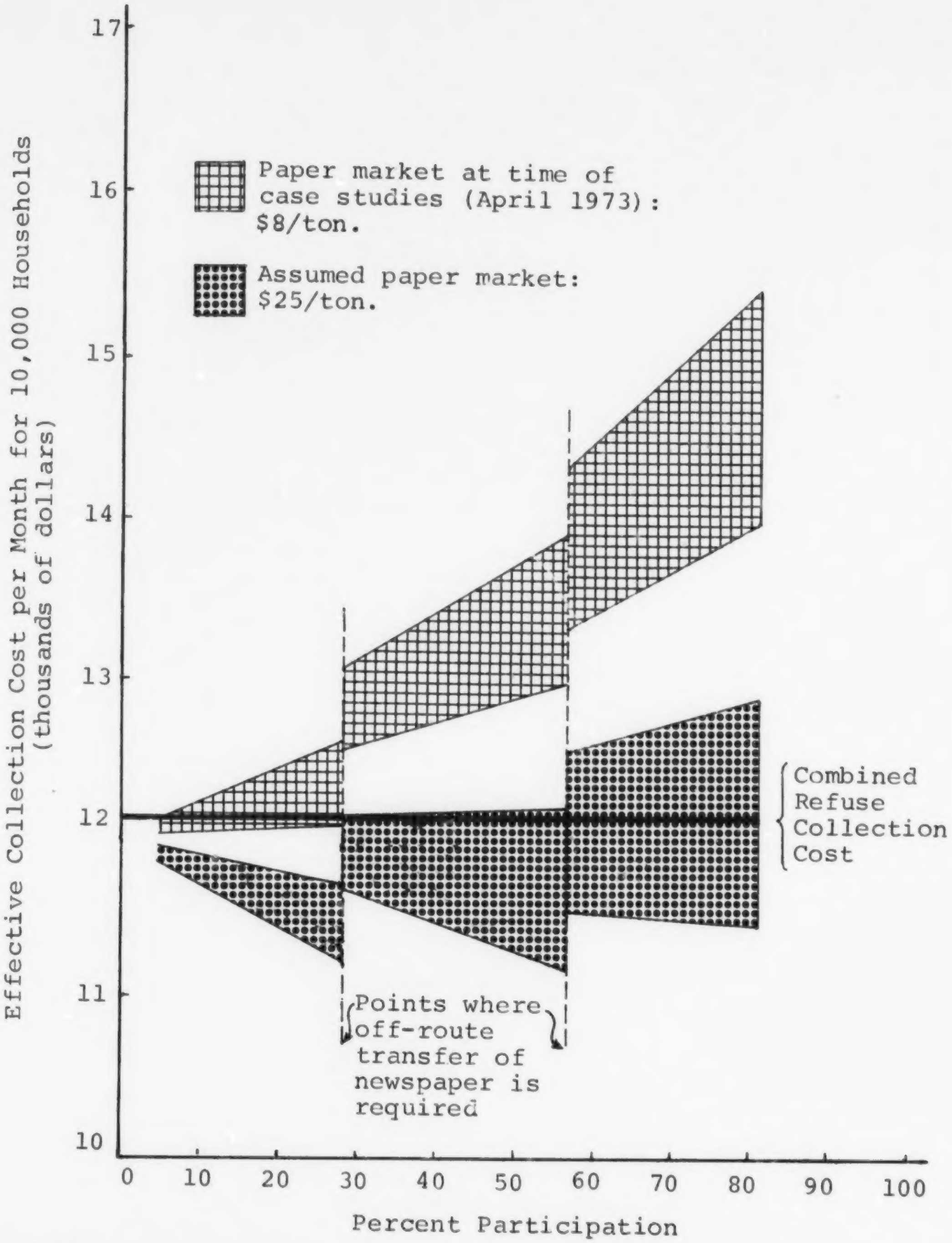

Figure 15. Effective cost for rack collection of separated newspaper versus combined refuse collection cost prior to system implementation: exemplary analysis for short haul situation.

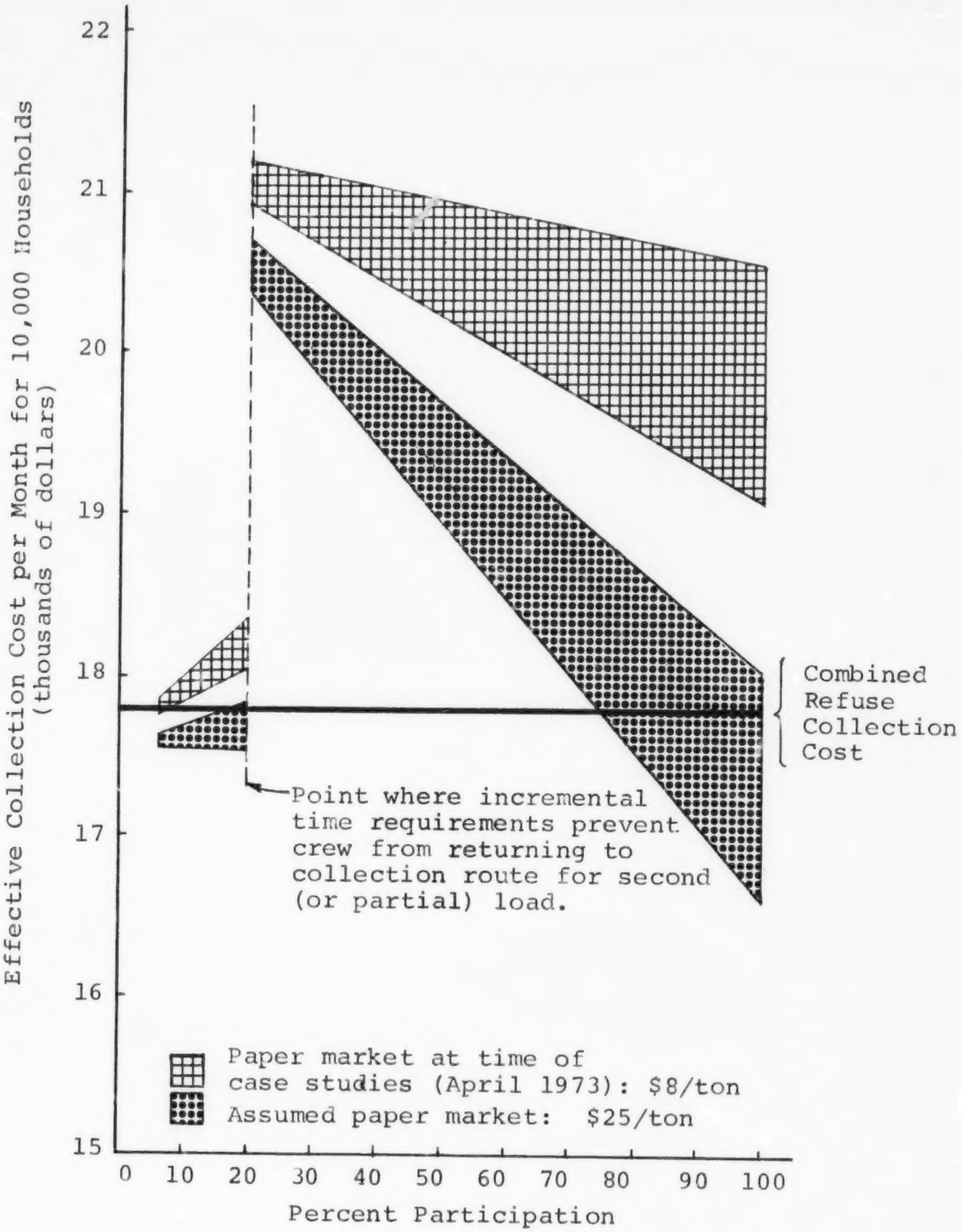

Figure 16 . Effective cost for rack collection of separated newspaper versus combined refuse collection cost prior to system implementation: exemplary analysis for long haul situation.

incinerator disposal costs were generally able to effectively decrease collection cost beyond a participation of 70 percent.

The long haul situation (Figure 16) portrays the impact of having the separate collection subsystem (i.e., the rack) off the collection route for extended lengths of time. The discontinuity at 20 percent participation in the long haul relationship represents the point in the hypothetical example where incremental time requirements become so severe that collection trucks are unable to collect more than one full load per day (i.e., there is not sufficient time for a truck to return to the route for a second load). Economic feasibility in the long haul example is indicated only at participation rates less than 20 percent and some situations exceeding 70 percent in conjunction with the $25 per ton revenue.

In practice the case study rack operations have been able to absorb the incremental time requirements without increasing the number of crews and/or equipment. The case study locations had also not attained participation in excess of 40 percent.

Economic application of the rack approach is thus limited by a number of factors. In some cases, features desired in an efficient collection system for mixed refuse are diametrically opposed to rack collection efficiency. For example:

- Truck capacity - as the capacity of the collection vehicle increases, so does the corresponding ability to stay on the route for greater lengths of time, a desired feature in mixed refuse collection systems. However, the need for transfer of newspaper before completion of a full truck load will increase accordingly.

- Compaction capability - similar to truck capacity, greater compaction with commensurately sized trucks will result in more on-route time and increased mixed refuse collection efficiency. Again, however, the need for transfer of rack-held newspaper will increase.

- Auxiliary engines - compaction between stops, reduced noise, and lower maintenance costs are often cited as justifying the use of an auxiliary engine on the collection vehicle. However, on some truck types, the space utilized for the engine is also the most suitable location for the rack.

- Diverted disposal quantities - paper revenues and diverted disposal savings increase with the quantities of paper collected. However, as participation in a rack program grows, the racks fill more quickly while the reduced quantities of mixed refuse allows the collection vehicle to remain even longer on the collection route.

Truck capacity and compaction capability have a subtle relationship. For example, a location using 16 cu yd compactors capable of achieving 500 lb per cu yd density would be a better candidate for rack collection use than a second location employing 20 cu yd trucks achieving 1,000 lb per cu yd density. Given equal crew efficiency, mixed refuse generation rate, and participation in a separate newspaper collection program, the collection trucks in the latter location could remain on route up to 2.5 times longer for each load. Accordingly, newspaper transfer would be required more frequently.

Conversely, in a community where existing resource recovery activity is substantial through local recycling centers or church/school paper drives, the rack approach to separate collection may operate economically with low generation rates, whereas the separate truck approach could not.

VII

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The assistance of the many public works administrators, private refuse collection firms, and concerned citizens who contributed information to the case studies comprising the basis for this study is gratefully acknowledged.

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APPENDICES

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APPENDIX A

INCURRED MATERIAL PREPARATION COSTS

Material preparation costs incurred by a householder may include costs for water used when rinsing or cleaning materials, energy used if metal container volume reduction requirements are accomplished with the aid of an electric can opener, and the amount of time used when bundling newspaper. Data to estimate the incurred costs were obtained during the voluntary household study conducted in conjunction with the primary study. This appendix delineates the amount of supplies and resources used and estimates the householder costs incurred for each of three material preparation activities: cleaning, volume reduction, and bundling.

Cleaning

The average time spent cleaning separated containers totaled 5.4 person-minutes per week. On a material by material basis the average weekly cleaning time and material amounts cleaned were as follows:

Material	Average weekly cleaning time (min.)	Average weekly generation rate (lbs)
Glass	2.4	4.5
Tin/bi-metal	2.3	1.7
Aluminum	0.7	0.3
Total	5.4	6.5

The average rate of water flow used during rinsing and cleaning of containers was computed to be approximately one gallon per minute (gpm). The cost of residential water was estimated to be $0.0005 per gallon based on a survey of water rates in the sixteen largest cities in the United States[16] (Note: case studies were conducted in nine of these cities). Water used during cleaning is dependent on the portion of time that water is actually used for cleaning purposes. For example, if dishwater is used both for container cleaning and for washing dishes, no incremental water cost was assigned for cleaning. Conversely, if tap water was kept running throughout the cleaning exercise, the total quantity of water was attributed to cleaning.

Participants in the household study did not use soap for cleaning separated containers, unless soap was in used dishwater. Similarly, mechanical dishwashers were not used for cleaning containers. Thus, no incremental costs were assigned for soap or for dishwasher use.

Table A-1 converts the time/quantity data above to incurred cleaning costs at the average water cost rate.

Based on average generation rates, Table A-2 presents the number of months required to produce one ton of each material and converts the cleaning cost per ton to a cost per household per month.

Volume Reduction

Aluminum containers can be readily crushed without mechanical assistance. Glass containers are not normally crushed in the household due to the potential hazards of broken glass. Therefore, tin/bi-metal containers were the only separated material to which incurred volume reduction costs were attributed.

Household studies indicated that when volume reduction was performed, an average of 2.2 minutes were spent crushing the 1.7 lbs of tin/bi-metal plated containers generated weekly. As an aid to volume reduction, the normal procedure was to cut the top and bottom from the container and flatten the resulting cylinder. Removing the container top is a utilitarian procedure and was therefore not attributable to material preparation costs. Removing the container bottom for ease of crushing was, however, and therefore an attributable material preparation cost.

Bottom removal may be accomplished manually with a hand-held can opener or mechanically with an electric can opener. Removing the container bottom consumed about 90 percent of the total crushing time with no significant time differences between the two removal methods. Assuming typical electric can opener has a rating of 160 watts, and electricity costs \$0.015 per KWH[16], the weekly cost of electricity was approximately \$0.00009 which is equivalent to about \$0.10 per ton of tin/bi-metal containers reduced in volume. As previously estimated, 278 months would be required to produce one ton of tin/bi-metal containers. Thus, when volume reduction was accomplished with the aid of an electrical can opener, the incurred household cost was about \$0.0004 per month. Conversely there was no incurred cost when manual aids such as a hand-held can opener were used (no hand-held can openers were purchased specifically for volume reduction during the household studies).

TABLE A-1

CLEANING COST CALCULATIONS

Material	Weekly water cost conversion (Gal/Wk)	x ($/Gal)	= ($/Wk)	Material generation (lbs/wk)	Cleaning cost ($/ton)
Glass	2.4	0.0005	0.00120	4.5	0.53
Tin/Bi-metal	2.3	0.0005	0.00115	1.7	1.35
Aluminum	0.7	0.0005	0.00035	0.3	2.33
Total/Average	5.4	0.0005	0.00270	6.5	0.83

TABLE A-2

CLEANING COSTS PER HOUSEHOLD

Material	Cleaning cost ($/ton)	Material generation Rate* (lbs/mo)	Time required to accumulate one ton of material per household+ (mo)	Incurred cost per household ($/mo)
Glass	0.53	19.3	104	0.0051
Tin/Bi-metal	1.35	7.2	278	0.0048
Aluminum	2.33	1.3	1,538	0.0015

*Based on generation rates determined from household study.
+Rounded to nearest whole month.

Bundling

Incurred bundling costs occur only when twine or a similar material is used to bind newspapers. Bundling serves to ease handling and reduces litter problems during collection or delivery. Grocery bags may be used to accomplish this purpose; however, no incremental costs were assigned if this method was used.

About 30 percent of the household participants voluntarily bundled newspaper with twine. About 2.6 ft of twine per week was used to bundle an average of 12.2 lbs of newspaper generated weekly. The cost of twine was estimated to be $0.001 per linear foot equating to a cost of $0.43 per ton. At a rate of 12.2 lbs per week (52.8 lbs per month) approximately 38 months would be required to generate one ton of newspaper. Thus, the incurred household cost per month was $0.011, or about a penny per month if bundling was accomplished with twine.

APPENDIX B

REVENUE AND DIVERTED DISPOSAL VALUES

Separately collected materials have a revenue value and a diverted disposal value. Each has a bearing on separate collection economics regardless of the approach used to evaluate a program.

Revenue

Revenue has an important influence on program economics. In March and April, 1973, when the case studies were conducted, wastepaper market prices ranged from $4 to $14 per ton with an average of $8 per ton. In March 1974, the same case study locations were receiving wastepaper revenues ranging from $12 to $56 per ton with an average of about $30 per ton. Glass and mixed metal revenues remained virtually unchanged, however, with glass programs ranging from $10 to $20 per ton ($15 per ton average) and mixed metal revenues at $10 per ton.

Diverted Disposal Savings

Savings in diverted solid waste disposal costs resulting from separate collection are principally dependent on whether the municipality operates its own disposal facility or pays a second party for disposal. In a secondary sense, the savings vary with the cost of the disposal method employed.

In the twenty-two case study locations (separate truck and rack), disposal was either by sanitary landfill or incineration. If the municipality pays a second party for disposal, the entire disposal cost per ton can be recovered through separate collection. If the disposal facility is owned and operated by the municipality, however, only a portion of the disposal cost can be saved. None of the case study locations in the latter category had attempted to quantify the portion of cost applicable to diverted disposal. Therefore, diverted disposal savings for landfill and incineration operations were estimated in the manner discussed below.

Sanitary Landfill. Benefits of separate collection on sanitary landfill operations include a decrease in the rate of use of remaining landfill space and a decrease in landfill equipment usage. Based on the case studies, reported sanitary landfill ownership and operating costs ranged from

$0.85 to $7.50 per ton with an average of about $2.50 per ton. Land costs were assumed to represent $0.50 of the total cost based on the disposal of 10,000 tons per acre and a net land cost of $5,000 per acre. Thus, separate collection of recyclables was assumed to potentially save $0.50 per ton in land costs at the sanitary landfill.*

The remaining $2 of the total $2.50 per ton was attributed to operating costs. Assuming a track dozer can spread and compact up to 80 tons of solid waste per hour[17] and that equipment and operator costs average $25 per hour, an additional operating cost savings of about $0.30 per ton can be attributed to wastes diverted by separate collection. Thus, a total diverted disposal cost savings of $0.80 per ton was assigned when a municipality owned and operated its own sanitary landfill while the total disposal cost per ton was assigned in cases where municipalities paid a second party for disposal.

Incineration. The diversion of materials from incineration through separate collection activities can be expected to reduce equipment usage and residue disposal requirements. Incineration costs reported for the case study locations ranged from $7.20 to $17.40 per ton with an average of $10.50 per ton. A breakdown of incinerator operating costs was provided for Chicago, Illinois[18] (a rack case study location). Table B-1 presents an estimated breakdown of incinerator cost elements believed to be affected as a result of refuse tonnage diverted via separate collection.

Assuming applicability of the tabulated data to the case study locations, savings from diverted materials amounts to 51 percent of the total cost per ton for incineration.

In addition, ash residue must be hauled for final landfill disposal. Residue transport costs vary with many factors, but for purposes of this study, savings were assumed to average $0.50 per ton of residue. Disposal cost of residue at the landfill was valued at $0.80 per ton for a municipally owned landfill and the total cost per ton for second-party ownership based on the preceding landfill discussion. A 95 percent reduction in weight of material was assumed for paper processed through an incinerator. No weight reduction was attributed to glass and metal if processed through an incinerator.

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*Fort Worth, Texas, was the only case study location that was able to provide an estimate for land costs: $0.57 per ton.

TABLE B-1

INCINERATION COST ELEMENTS AS A PERCENTAGE OF TOTAL PLANT OPERATING COSTS

Operating cost element	Percent of total operating cost	Applicable to diverted tonnage
Operating less residue disposal	27	27
Maintenance and repair	22	22
Administration and supervision	8	0
Pension	4	0
Fuel and utilities	2	2
Amortization	20	0
Miscellaneous	17	0
	100	51

APPENDIX C

COLLECTION MODEL

The many approaches to performing refuse collection and/or separate collection of recyclable materials can be described with a mathematical model. The model defines the mathematical relationships between collection time, tonnage collected, haul time, equipment capacity, costs, and other factors. Through repeated calculations, the model may be used to analyze alternative collection approaches to minimize and/or compare applicable costs.

The following factors affecting the efficiency of mixed or separate refuse collection were included as variables in the model:

1. Average quantity of mixed or recyclable material(s) generated per residential unit.
2. Average collection time for each residential unit, including travel time to the next stop.
3. Average driving time between the route and the disposal site (secondary material dealer, transfer facility, or final disposal site).
4. Total non-productive time: travel time between yard (vehicle storage area) and route and between the disposal site and the yard; breaks (lunch, coffee, relief); and dispatch.
5. Average offloading time per load at the disposal site.
6. Crew size.
7. Equipment type, capacity, and performance characteristics.

The following assumptions were used during the calculations:

1. The minimum partial load allowed was one-fourth of the vehicle load capacity (i.e., a collection vehicle was not allowed to return to the collection route after emptying a full load unless sufficient time remained to collect at least a quarter of a load).

2. The maximum work day was constrained to 480 minutes.

3. Crew members were paid for eight hours (480 minutes); if time was not sufficient to collect a partial load, they were dismissed early, but paid for 8 hours.

Physical and cost variables used in the model were defined as follows:

Physical Variables

X_n: Total time to collect and offload n loads (crew min/day).

V_c: Vehicle capacity (cu yd).

t: Average collection time per stop plus travel time to the next stop (min).

d: Average density of material in the vehicle (lbs/cu yd).

Q: Average quantity of material per stop (lbs).

B: Average one-way driving time between route and disposal site (min).

D: Average disposal time (min).

K: Total non-productive time per day - includes dispatch, breaks, yard to route time, and disposal site to yard time (min).

Cost Variables

C_c: Cost of collection labor ($/crew-min).

C_v: Cost of collection vehicle ($/truck-min).

R: Revenue from materials separately collected ($/ton).

S: Disposal savings from materials separately collected ($/ton).

Alternative collection frequencies may be evaluated by changing the value of the average quantity of material collected per stop (Q) in proportion to the monthly generation rate. For example, evaluation of a separate newspaper collection program where once per month collection is to be performed and the average residential generation rate is 40 lbs/mo would have a Q value of 40 lbs. If weekly collection is to be evaluated, a Q value of 9.2 lbs would be used (40 ÷ 4.33 weeks/mo).

Various participation rates may be evaluated by changing the value of the average collection time per stop (t). As previously defined, the value of t is comprised of the time to collect materials per stop (i.e., dismount truck, load, remount truck) plus the driving time to the next stop. The collection portion of t is assumed to a constant at a specific collection frequency due to the average quantity of material collected per stop being held constant.

The second variable in the time calculation, travel time to the next stop, is a function of participation rate. An even distribution of participants and material generation along a 10-home segment of a route should be assumed. For example, if an overall participation rate of 10 percent is to be evaluated and one side of the street collection is performed, the assumption that one out of each ten homes along the route would be made. Thus, travel time would be calculated based on collecting materials at the first home on the route and driving past the subsequent nine homes to the next participant. Similarly, a 50 percent participation rate may be evaluated by assuming a collection stop is made at every other home along the route.

Calculations

Using the variables discussed above, a series of seven calculations are necessary to evaluate the performance and cost characteristics of collection operations:

1. Calculate the time to collect the first and successive loads.
2. Convert collection time into collection cost.
3. Determine tonnage collected.
4. Determine number of residences served.
5. Convert tonnage collected into dollar savings (revenue plus diverted disposal savings).
6. Compute net cost of separate collection (collection cost less savings).
7. Convert net cost into meaningful factors (cost/ton, cost/residence).

Step 1: Collection Time Calculation

The total time in minutes to complete one load (collect and offload) can be calculated as follows:

$$X_1 = \frac{V_c td}{Q} + B + D + K$$

At the disposal site, a decision is made:

If $X_1 + 2B + D = 480$, only one full load will be collected for the day;

if $X_1 > 480$, only a single partial load will be collected for the day, and the following calculation is made:

$$480 = (a)\frac{Vtd}{Q} + B + K + D.$$

Solving for the value of (a) gives the fraction of the truck capacity used for the partial load;

if $X_1 + 2B + D < 480$, the truck is sent for a second or more loads as time permits.

In general, the truck makes a total of n trips, where:

$$X_n: = (n + a - 1)\frac{V_c td}{Q} + (2n - 1) B + K + nD$$

provided $X_n \leq 480 \leq X_{n+1}$, and $a \geq 1/4$;

if $a < 1/4$, only $(n - 1)$ trips are made.

The results provide the collection time in terms of crew-minutes per day and the quantity of material collected by the vehicle. In this case, crew members were paid for a 480 min day even if finished early. If collection time were not constrained and overtime permitted, appropriate modifications would be required to the preceding equations.

Step 2: Collection Cost Calculation

Under the conditions imposed, crew members are paid for a full day's work even if finished early. This condition will not always be the case. Therefore, labor costs should be converted to a cost per crew per min ($/min) based on the cumulative hourly rates of driver and loaders including overhead and/or fringe benefits to readily convert the daily collection time, X_n, into labor costs. Similarly, vehicle costs (amortization, overhead, fuel, oil, and maintenance) should be converted to a cost per vehicle per minute ($/min) so that vehicle costs can be apportioned. Generally, daily collection time can be converted to cost as follows:

$$\text{Daily Collection Cost} = X_n \ (C_c + C_v)$$

When an undertime situation occurs, the collection cost relationship is as follows:

$$\text{Daily Collection Cost} = 480\ C_c + [480 - (480-X_n)]\ C_v$$

This relationship credits undertime for vehicle usage.

Step 3: Tonnage Collected Calculation

Revenue is based on tonnage of recyclable materials collected. The volume of material collected per day can be converted to tonnage by the following relationship:

$$\text{Tonnage Collected} = \frac{\Sigma\ Vd}{2{,}000}$$

The volume (V) may be calculated by multiplying the truck capacity (V_c) by the number of full and partial loads collected in Step 1. Average density (d) is derived from weighings of loaded vehicle weights, subtracting the vehicle tare weight, and dividing by V_c.

Step 4: Residences Served Calculation

The number of residences served per day by each crew depends on many factors: participation rate, truck volume, crew size, etc. The factors required to estimate residential service rate, however, will have been developed during Step 1. Thus, the service factor may be estimated by dividing the multiplicative sum of the volume collected and density by the average quantity of materials per stop:

$$\text{Services} = \frac{\Sigma\,Vd}{Q}$$

Step 5: Dollar Savings Calculation

Revenue (R) from recyclable materials and diverted disposal savings serve to reduce overall collection costs. Revenue is readily calculated by multiplying tonnage collected (Step 3) by the rate paid by a secondary materials dealer for a specified material.

Diverted disposal savings (S) are calculated based on local disposal conditions. These savings should consider first and second party costs. For example, if Municipality A is paying private landfill operator B for disposal, the entire unit disposal cost should be credited to the separate collection operations for each ton of material diverted. However, if Municipality A owns and operates the landfill, only a portion of the unit cost should be attributed to the diverted materials. (A sum of $0.80/ton was used as a proxy for these "first party" landfill diverted disposal costs.)

Incineration costs should be handled similarly. Municipalities paying a second party for incineration should credit the entire unit cost to separate collection operations. As a proxy for first party diverted disposal costs, 50 percent of the incineration costs can be used (based on cost allocation of Chicago incinerator costs)[18] plus incinerator residue disposal costs (again allocated on a first-and-second party basis).

Step 6: Net Collection Cost Calculation

The net cost of separate collection operations is calculated by subtracting the results of Step 5 from the results of Step 2:

$$\text{(Total separate collection cost)} - \text{(Revenue plus diverted disposal cost)} = \text{(Net separate collection cost)}$$

or

$$\text{(Step 2)} - \text{(Step 5)} = \text{Step 6}$$

Step 7: Performance Factor Calculation

Based on the net cost calculation (Step 6), performance measures such as cost/ton and cost/residence can be calculated. Net cost per ton is calculated by simply dividing cost by the tonnage collected:

$$\frac{\text{Net Cost per Day}}{\text{Tonnage Collected per Day}} \text{ or } \frac{\text{Step 6}}{\text{Step 3}}$$

The cost per residence per month is calculated by dividing the daily cost by the number of residences serviced per day (Step 4) and multiplying this sum by the collection frequency (in terms of collections per residence per month):

$$\text{Cost per Residence} = \frac{\text{Net Cost per Day}}{\text{Number of Residences Served per day}} \times \text{Collections per Residences per Month}$$

or

$$\frac{\text{Step 6}}{\text{Step 4}} \times \begin{array}{c}\text{Collection Frequency}\\ \text{Factor}\end{array}$$

where

Frequency of Collection	Factor
Once per month	1
Once per 2 weeks	2.16
Once per week	4.33

APPENDIX D

SEPARATE TRUCK SYSTEMS ANALYSIS

The analysis to assess the optimal impact of separate collection operations via the separate truck approach with respect to overall collection costs* is presented in this appendix. The analysis presented herein was performed using the adapted collection model described in Appendix C. The model output estimates collection costs prior to implementing a separate collection subsystem and the effective cost of collection after implementation of separate collection. The effective cost accounts for rerouting of mixed refuse collection vehicles reflecting reductions in quantity of waste per stop due to separate collection of newspaper.

The conditions analyzed are shown in Table D-1. As shown, the analysis considers variability in mixed and separate collection parameters in terms of: truck capacity, crew size, collection frequency, haul distance, disposal savings, revenue received from newspaper sales, and percent participation in the separate collection program.

Data Development

Data used to exercise the model are presented in Table D-2 and discussed in the ensuing text.

Collection vehicle capacity (V_C) for mixed refuse collection operations were 16, 20, and 25 cu yd when rear-loading compactor vehicles were considered, and 20 and 25 cu yd for side-loading compactors. Separate collection alternatives considered 12, 16, 20, 25 cu yd rear-loaders and 20, 25 cu yd side-loaders. The vehicle costs (C_V) were estimated to be $3 per hr ($0.050 per min) for the 12 cu yd truck; $4 per hr for 12 and 20 cu yd trucks ($0.067 per min); and $5 per hr for the 25 cu yd trucks ($0.083 per min).

Crew costs were based on national averages[12], plus 25 percent fringe benefits. Drivers pay rates were $5.80 per hr and loader rates were $4.70 per hr. Thus, a one-man crew (driver) was valued at $0.098 per min for an 8-hr work day. Correspondingly, a two-man crew (driver and loader) at $0.174 per min and a three-man crew (driver and two loaders) at $0.254 per min.

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*Overall collection costs considers the costs of both mixed and separate collection.

TABLE D-1

CONDITIONS ANALYZED VIA THE ADAPTED REFUSE COLLECTION MODEL

Variable	Mixed Collection	Separate Newspaper Collection
Crew Size (no./vehicle)	1-Side loader 2, 3 Rear loader	1-Side loader 2, 3 Rear loader
Collection frequency	1/wk, 2/wk	1/wk, 1/2wk, 1/mo
Collection location	curb	curb
Vehicle capacity (cu yd)	16,20,25 rear loader 20,25 side loader	12,16,20,25 rear loader 20,25 side loader
Generation rate (lbs/household/wk)	61*-1/wk coll'n 79⁺-2/wk coll'n	7 (newspaper only)
Labor cost	National average# $5.80-driver $4.70-loader	National average# $5.80-driver $4.70-loader
Haul distance	Short haul, long haul	Short haul
Disposal savings	----	Landfill and incineration (first and second party costs)
Revenue ($/ton)	----	8,25
Percent participation	----	20,50,80

*Based on 2.5 lbs per person per day and 3.5 persons per household.

+Based on research by Quon, generation rate increases with collection frequency.[14]

#Includes 25 percent fringe benefits.

TABLE D-2

DATA FOR EXERCISING THE COLLECTION MODEL
-SEPARATE TRUCK APPROACH-

Variable	Mixed Refuse Collection						
	Prior to Sep. Collection	After Sep. Collection/ Participation Rate			Separate Collection/ Participation Rate		
		20	50	80	20	50	80
V_c (cu yd)							
Rear loader	16, 20, 25	16, 20, 25			12, 16, 20, 25		
Side loader	20, 25	20, 25			20, 25		
t (min)							
Mixed: 1/wk							
. 1-man	.76	.76	.75	.74			
. 2-man	.69	.68	.67	.66			
. 3-man	.60	.60	.59	.58			
Mixed: 2/wk*							
. 1-man	.68/.59	.68/.59	.67/.58	.66/.57			
. 2-man	.61/.52	.61/.51	.60/.51	.59/.50			
. 3-man	.54/.46	.54/.46	.53/.45	.52/.44			
Sep.: 1/wk							
. 1-man					.51	.33	.24
. 2-man					.49	.31	.22
. 3-man					.48	.30	.21

TABLE D-2 (Continued)

Variable	Mixed Refuse Collection				Separate Collection/ Participation Rate		
	Prior to Sep. Collection	After Sep. Collection/ Participation Rate					
		20	50	80	20	50	80
Sep.: 1/2 wk							
. 1-man					.53	.35	.26
. 2-man					.51	.33	.24
. 3-man					.50	.32	.23
Sep.: 1/mo							
. 1-man					.59	.41	.32
. 2-man					.56	.38	.29
. 3-man					.54	.36	.27
d (lb/cu yd)	650		650			650	
Q (lbs) Mixed							
. 1/wk	61	60	57	55			
. 2/wk*	47/32	46/31	45/30	44/29			
Separate					7	14	30
B (min)							
. Long haul	15		15			15	
. Short haul	45		45			15	

TABLE D-2 (Continued)

Variable	Mixed Refuse Collection				Separate Collection/ Participation Rate		
	Prior to Sep. Collection	After Sep. Collection/ Participation Rate					
		20	50	80	20	50	80
D (min)	15	15			15		
K (min)	120	120			120		
C_V ($/min)							
. 12 cu yd					.050		
. 16,20 cu yd	.067	.067			.067		
. 25 cu yd	.083	.083			.083		
C_C ($/min)							
. 1-man	.098	.098			.098		
. 2-man	.174	.174			.174		
. 3-man	.254	.254			.254		

*Reflects time or weight estimates for first/second collection day per week.

The average compacted density of combined refuse (d) with or without newspaper, was assumed at 650 lbs per cu yd. Compacted newspaper was also estimated at 650 lbs per cu yd based on measurements taken in Fort Worth, Texas.[10]

The average normal quantity of combined refuse per stop (Q) for once per week mixed refuse collection was calculated based on 3.5 persons per residence and 2.5 lbs of solid waste generated per person per day. The resulting average quantity of residential solid waste per stop was estimated to be 61 lbs per week. Assuming 7 lbs of newspaper per household per week, the remaining quantity of combined refuse with all newspaper removed (100 percent participation rate) was 54 lbs. The quantity of combined refuse per collection stop at the exemplary 20, 50, and 80 percent participation rates was calculated assuming participating stops generate 54 lbs and non-participating stops generate 61 lbs of combined refuse on a weekly basis. For those combinations involving twice weekly collection, the normal quantity was assumed to increase 30 percent (to 79 lbs per week), with 60 percent of the total collected on the first collection day of the week and the remainder collected on the second day.[11]

The average times per stop (t) for collection of mixed refuse prior to and after separate collection of newspaper were derived from studies of solid waste collection systems comparing one-man and multi-man crews[13] based on the following rationale.

Containers for storage of combined refuse were assumed to be 32-gal metal or plastic containers. Container utilization was estimated to average 91 percent with an average loose refuse density of 163 lbs per cu yd.[19] Based on these factors, the required number of storage containers were computed and tabulated in Table D-3. Separate collection of newspaper should reduce the number of storage containers (on the average) required for the remaining refuse. Since newspaper quantities are relatively small compared to the total quantity of mixed refuse, a rational method for the assessment of container requirements was sought. Graphical data describing the number of containers per stop was found to resemble the Poisson statical distribution. (The general form of the distribution is depicted in Figure D-1.[20]) Using the average number of refuse containers per stop from Table D-3 in conjunction with the Poisson distribution, the probability associated with finding certain numbers of storage containers per collection stop was calculated.

TABLE D-3

ESTIMATED NUMBER OF STORAGE CONTAINERS FOR RESIDENTIAL REFUSE

Refuse Collected	Collection Frequency	Avg. No. of Containers Per Stop
Mixed refuse	1/wk	2.60
Mixed refuse less newspaper	1/wk	2.34
Mixed refuse	2/wk (1st day)	2.04
	(2nd day)	1.32
Mixed refuse less newspaper	2/wk (1st day)	1.83
	(2nd day)	1.24

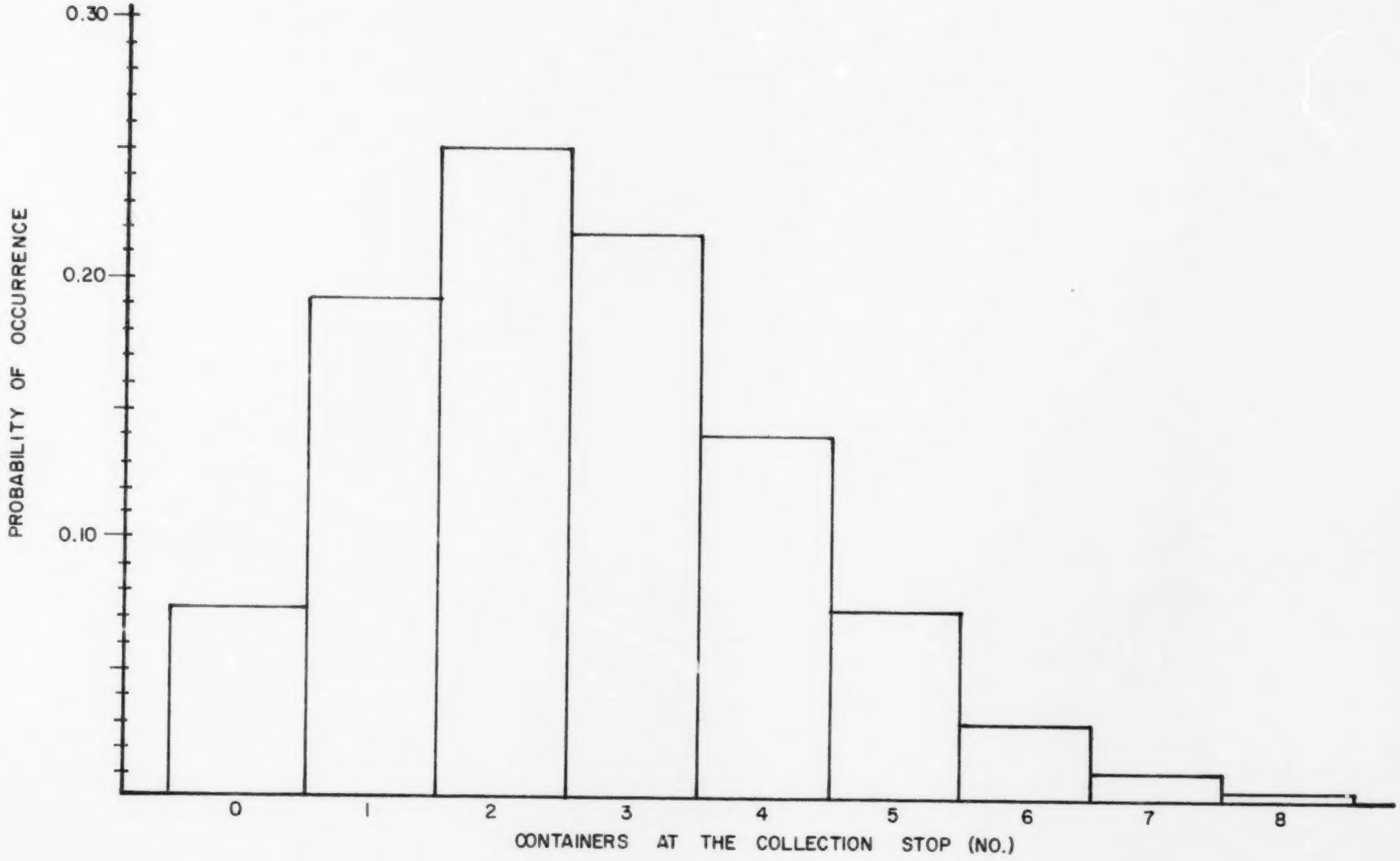

Figure D-1. General form of the Poisson distribution.

Results are presented in Table D-4. Because a twice weekly collection system must be sized for the "heavier" collection day, the tabulation presents the probability values for containers on the first collection day of the week only.

The estimated crew times to service containers were derived from time study data presented in reference 13 and tabulated in Table D-5.

The container probability data and the container collection time data were used to estimate the collection time per stop for the various collection combinations. The collection time estimates are presented in Table D-6. In addition to container handling times, the tabulated amounts include travel time between stops on the route.

TABLE D-5

ESTIMATED AVERAGE COLLECTION TIME (minutes)

Crew size	Pick-up location	Containers (no.) 1	2	3	4	5 or more
1-man	Curb	0.28	0.46	0.62	0.79	1.20
2-man	Curb	0.22	0.38	0.56	0.71	0.90
3-man	Curb	0.21	0.31	0.45	0.56	0.75

The average loading times per stop for separate collection of newspaper were based on time studies of three-man separate collection crews in Fort Worth, Texas[10], in areas provided with both weekly and bi-weekly separate collection service. These studies resulted in the following relationship:

$$\text{Newspaper Loading Time} = 0.05 + (0.004)\,(\text{average quantity collected per stop}) = \text{min/stop}$$

The resulting loading times for three-man crews were adjusted to derive analogous times for one and two-man crews based on the ratios determined in the development of mixed refuse loading times.

TABLE D-4

STORAGE CONTAINER PROBABILITY PER COLLECTION STOP

Refuse Collected	Collection Frequency	Probability/Containers				
		1 or less	2	3	4	5 or more
Mixed refuse	1/wk	0.27	0.25	0.22	0.14	0.12
Mixed refuse less newspaper	1/wk	0.32	0.26	0.21	0.12	0.09
Mixed refuse	2/wk	0.39	0.27	0.18	0.10	0.06
Mixed refuse less newspaper	2/wk	0.45	0.27	0.16	0.08	0.04

TABLE D-6

ESTIMATED COLLECTION AND TRAVEL TIME PER STOP

Refuse Collected	Collection Frequency	Pick-up Point*	Crew Size	Time Per Stop (min)		
				Container Collection	Travel to Next Stop	Total
Combined refuse collection						
Combined refuse	1/wk	C	1	0.56	0.20	0.76
	1/wk	C	2	0.49	0.20	0.69
	1/wk	C	3	0.40	0.20	0.60
Combined refuse less newspaper	1/wk	C	1	0.54	0.20	0.74
	1/wk	C	2	0.46	0.20	0.66
	1/wk	C	3	0.38	0.20	0.58
Combined refuse	2/wk	C	1	0.48	0.20	0.68
	2/wk	C	2	0.41	0.20	0.61
	2/wk	C	3	0.34	0.20	0.54
Combined refuse less newspaper	2/wk	C	1	0.46	0.20	0.66
	2/wk	C	2	0.40	0.20	0.60
	2/wk	C	3	0.32	0.20	0.52

* C: Curb

In addition to loading time, travel time between stops varies with respect to participation rate, street frontage per household, and collection methodology* among other variables. Separate collection from the curb on one side of the street at a time was assumed and travel time between stops for separate collection simulated based on truck acceleration to 10 mph between participating stops. The results of this simulation are shown in Figure D-2 for households with 40 ft and 100 ft street frontages at various participation rates.# Figure D-2 was then used to estimate travel time between stops at 20, 50, and 80 percent participation rates for an assumed street frontage of 50 ft per residence. These estimated travel times were added to the estimated loading times and recorded in Table D-2.

The average one-way driving time between the collection route and the disposal site (B) for mixed refuse collection trucks was assumed to be 15 min for typifying a short haul situation and 45 min for a long haul situation. One-way driving time between the collection route and the secondary materials dealer was assumed to be 15 min to exemplify the impact of separate collection when long haul of mixed refuse is required.

The average time spent by the collection vehicle at the disposal site or secondary materials dealer for emptying a full load of mixed refuse or newspaper (D) was assumed to be 15 min.

Non-productive time (K) for such functions as dispatch, lunch and relief, yard to route time, and disposal site to yard time was assumed to total 120 min per day.

Collection vehicles were allowed to return to the route after collecting a full load of refuse or newspaper if at least 25 percent of another full load could be collected within the working day. No overtime was allowed.

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*Collection methodology considers such variables as truck type (side loader, rear loader), collection point (alley, curb, on-property), collections made from one or both sides of the street, etc.

#If two sides of the street collections are performed, the same approach may be used although the probability of stop is more complex than one side collection. Instead of using a continuous 10-home segment, a 5-home segment is used with homes on both sides of the street considered. "Two-side" calculations, however, were beyond the scope of this study and left to the reader.

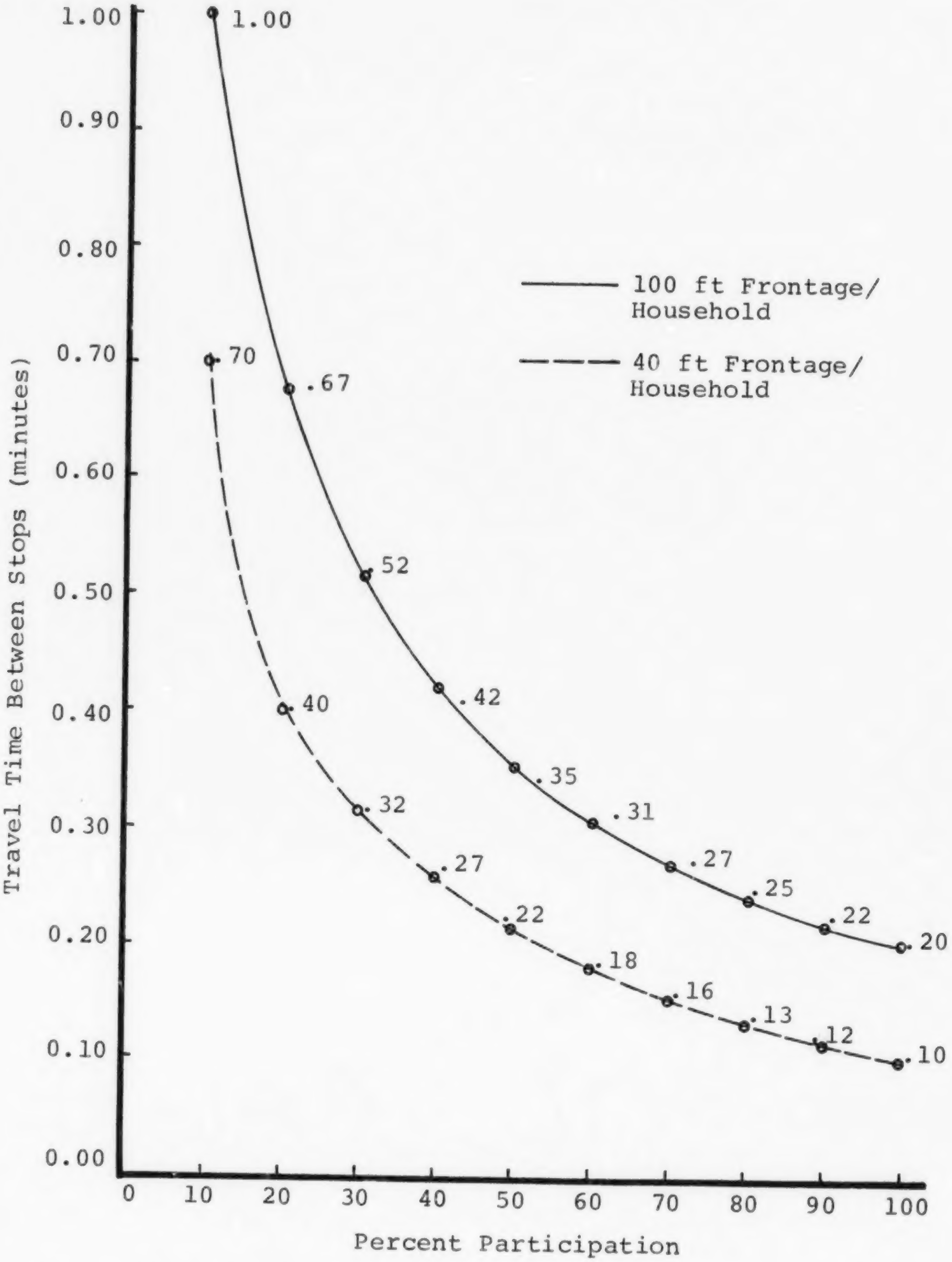

Figure D-2 : Average travel time between stops at various participation rates.

The additional time allocated for collection of a subsequent full or partial load included 15 min to return to the collection area from the disposal site or secondary materials dealer and another 15 min for driving time between the route and the disposal site/dealer to dispose of the partial load. Fifteen minutes were again allowed for disposing the partial load.

Model Results

Although being too extensive to delineate each of the more than 1,200 combinations resulting from the variables listed in Table D-1, the printout accompanying this report can be used as a tool to provide insight into the potential impact of separate collection on overall solid waste collection costs. As stated in the body of the report, if municipal conditions are significantly different from those tabulated, the model may be used to obtain applicable results by inserting local variables and/or conditions. For example, only curb pick-up of mixed refuse and separated newspaper was evaluated. Municipalities providing on-property service for mixed refuse should insert applicable information and exercise the model rather than attempt use of the tabulated data. Similarly, municipalities that estimate the average weight of newspaper per household to significantly exceed the 7 lbs per week used in the model would again be advised to exercise the model using applicable conditions. The model is not extremely complex although time should be taken to obtain applicable data if the model is to be used. As a predictive tool, the model results will be as good as the input data.

In order to exemplify the use and value of the model output, six alternative collection situations were selected:

	Crew Size (no./vehicle)		Compactor Vehicle		Mixed Size Collection Frequency (no./wk)
Situation No.	Mixed	Separate	Type (loading location)	(cu yd)	
1	3	3	Rear	20	1
2	3	2	Rear	20	1
3	1	1	Side	20	1
4	3	3	Rear	20	2
5	3	2	Rear	20	2
6	1	1	Side	20	2

The first and fourth situations were selected to typify the "average" municipal case study. These parameters included use of three man crews for both mixed and separate collection from the curb with 20 cu yd rear-loading compactors. Aside from changing mixed collection frequency, the only modification in the parameters of the second and fifth situations was reduction of separate collection crew size from three to two. The third and sixth situations represent minimization of crew size for both mixed and separate collection. For the purpose of illustration, mixed refuse collection frequency was fixed while separate collection frequency was varied. Results are shown in Figures D-3 through D-8. Information is presented for separate collection frequencies of 1/wk, 1/2 wk and 1/mo. The dual set curves for each collection frequency represent differences due to long and short haul situations.* The tandem curves shown for long and short haul situations represent the difference in economic feasibility resulting from a change in revenue from an average of $8/ton to an updated market price of $25/ton. The respective bands at each revenue rate represent the difference in diverted disposal cost savings between a city operating its own landfill to a city using a non-owned incinerator.

Separate collection is seen to have a more immediate impact in long-haul situations due to reductions in long-haul of mixed refuse. Similarly, savings attributed to quantities diverted from incineration have a higher payoff than quantities diverted from a landfill. Another logical consistency is that once per month separate collection in conjunction with mixed collection represents the least cost combination.#

The variation in curve shape is due to the effect that revenue and disposal savings have on total collection costs at various separate collection frequencies. In essence, revenue and disposal savings have a dampening effect on overall collection costs. In certain instances these savings are not sufficient to dampen overall costs to a point where an effective cost decline results. Cost is the most sensitive to collection frequency and labor, and least sensitive to truck capacity (based on an assessment of all capacities listed in Table D-1).

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*Long and short haul situations were depicted in the model calculations by assuming respective one-way haul times of 15 min and 45 min.

#The effect of lesser quantities of recyclable materials being placed out for collection as the collection frequency is lengthened was determined after the model results were documented.

The importance of reducing separate collection crew size at the once per week separate collection frequency is shown by comparing Figures D-3 and D-4, and D-6 and D-7. Using the combined refuse collection cost (designated on the Figures) as a baseline situation, reduction of separate collection crew size from 3 to 2 results in a breakeven situation occurring with about 30 to 40 percent less participation at the 1/wk separate collection frequency. Reducing crew size at the 1/2 wk and 1/mo separate collection frequencies resulted in breakeven situations occurring with 5 to 10 percent less participation. This apparent decline in impact is due to the relationship between quantity of newspaper per stop and crew size (i.e., at once per week a crew collects 7 lbs per stop; at bi-weekly or monthly frequencies, the crew would respectively collect 14 or 30 lbs, inherently resulting in greater efficiency). Thus, economies of scale are apparent.

The situations hypothesizing one-man collection situations depict the least cost solutions for residential solid waste collection prior to and after separate collection implementation. The effect of lessening costs in almost every situation depicted in Figures D-5 and D-8 results from newspaper revenue and diverted disposal savings being able to overcome equipment and one-man labor costs at a faster rate than if two or three times the labor is used to collect identical quantities of waste (mixed or separate) when larger crews are used.

Regardless, the six illustrations typify the value of using the model in local decision making. Without a costly trial and error procedure, various service levels can easily be hypothesized, breakeven situations assessed, and savings and/or costs estimated.

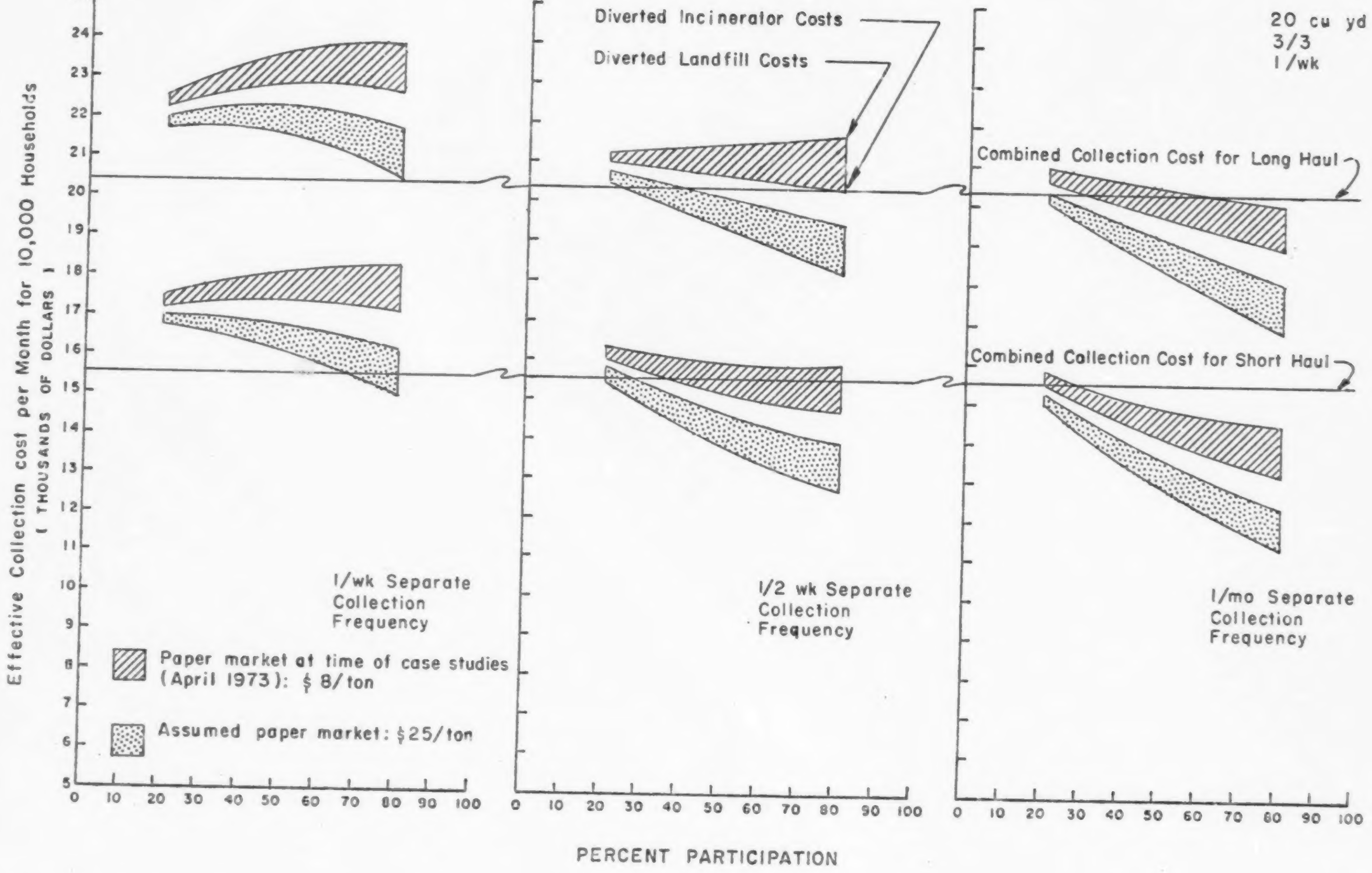

Figure D-3. Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed once per week, 3 man separate collection crew.

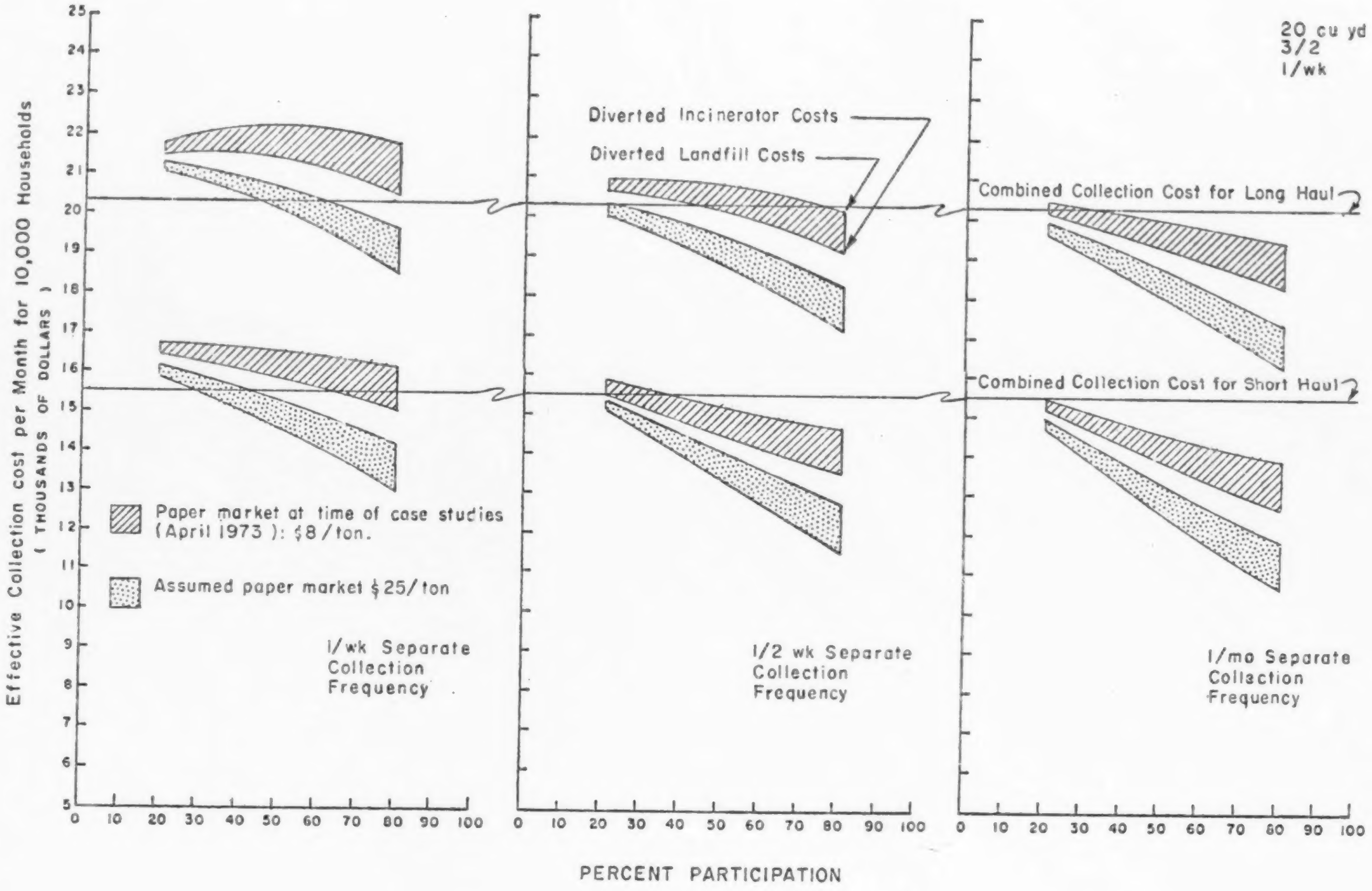

Figure D-4. Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed once per week, 2 man separate collection crew.

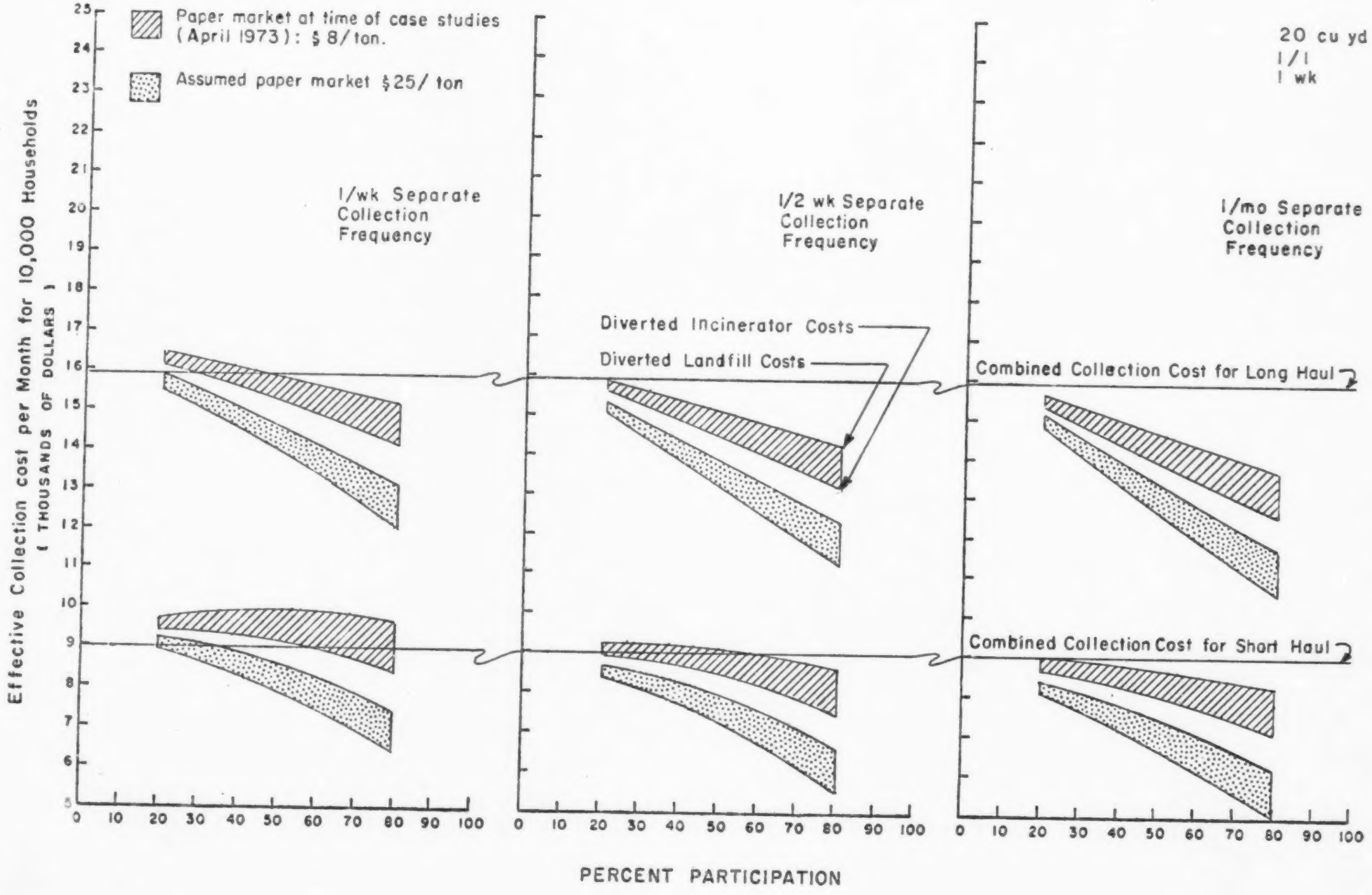

Figure D-5. Impact of optimizing refuse collection operations: exemplary analysis, 1 man mixed refuse collection performed once per week, 1 man separate collection crew.

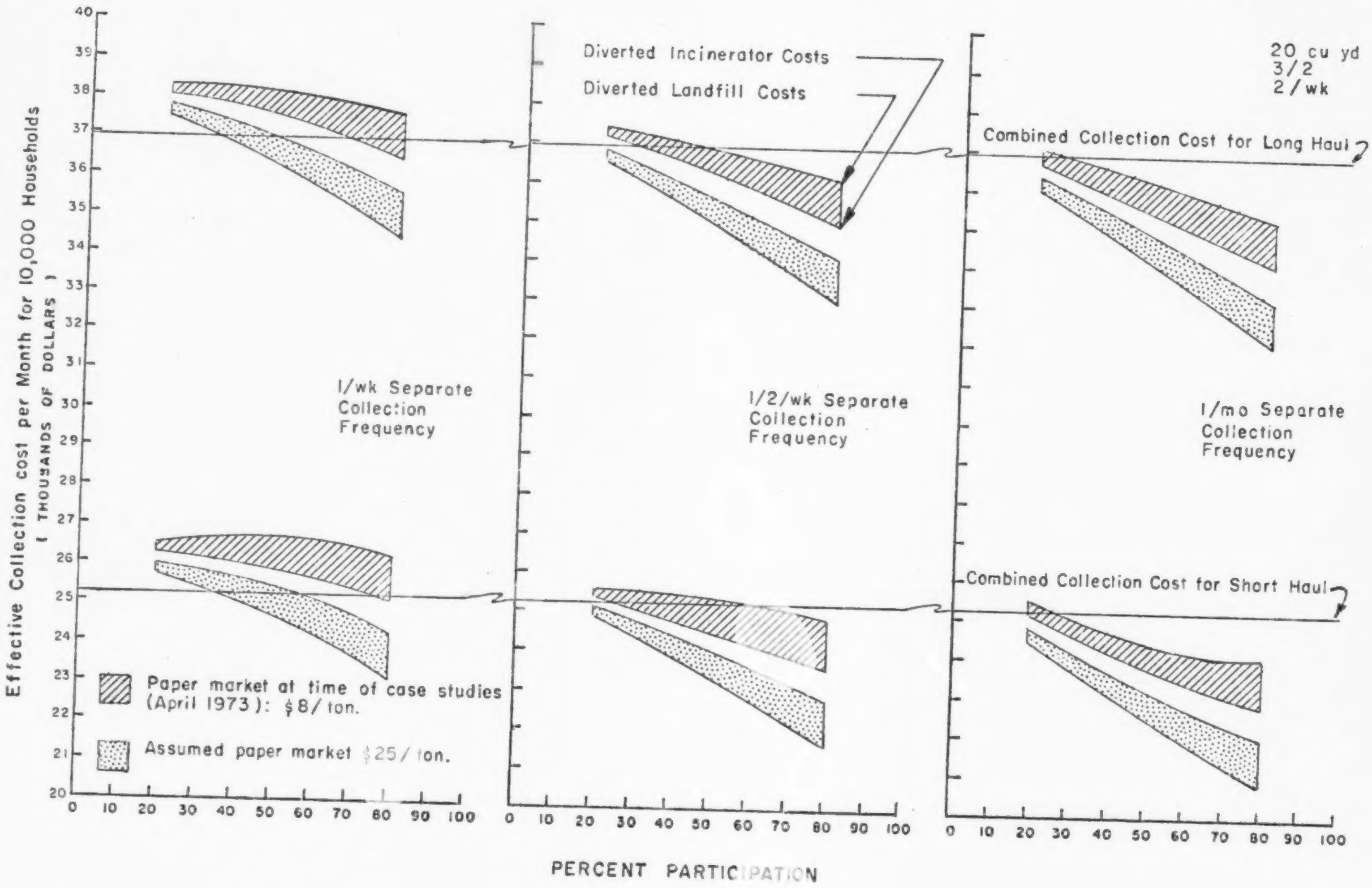

Figure D-6 Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed twice per week, 3 man separate collection crew.

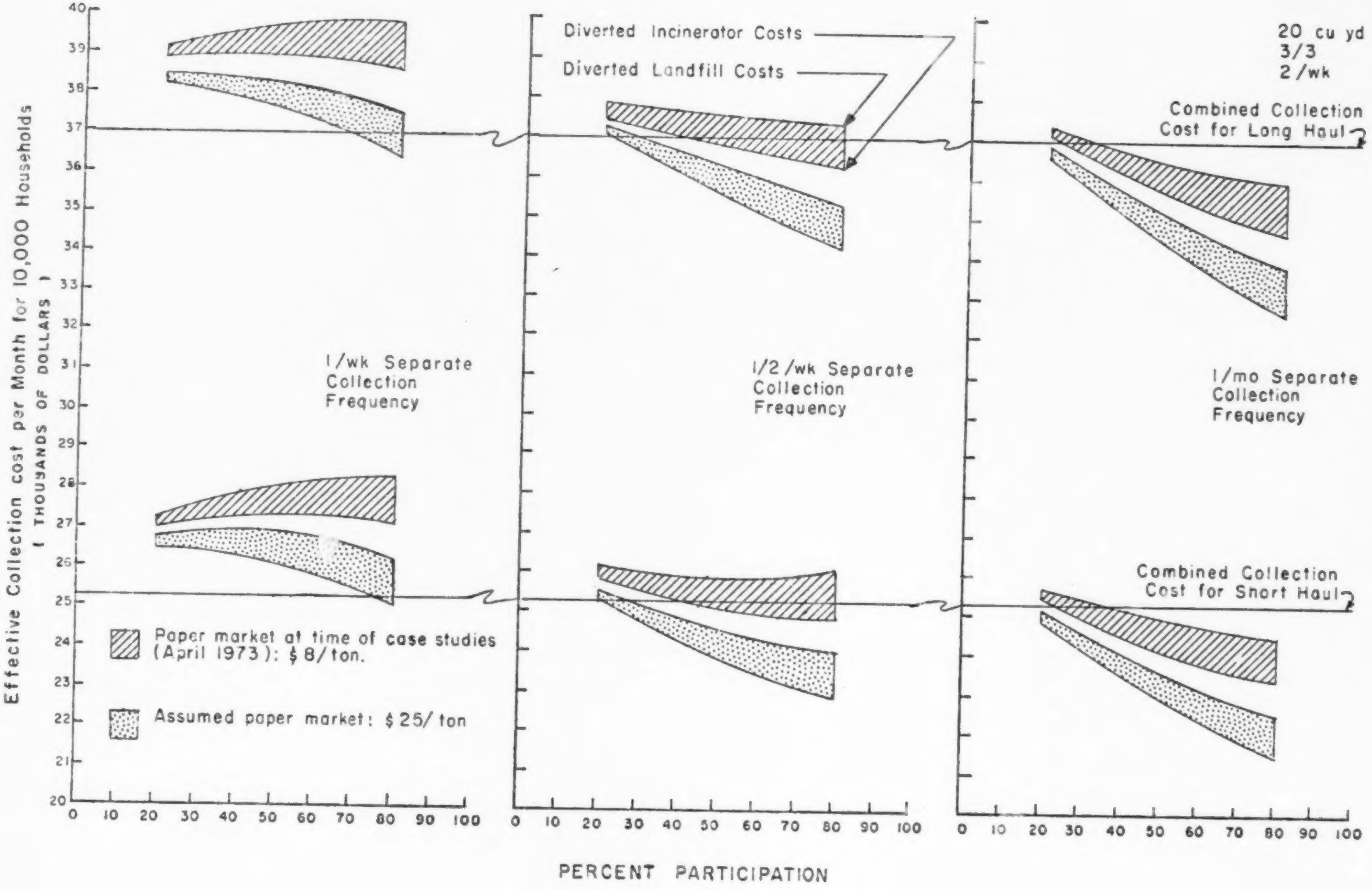

Figure D-7. Impact of optimizing refuse collection operations: exemplary analysis, 3 man mixed refuse collection performed twice per week, 2 man separate collection crew.

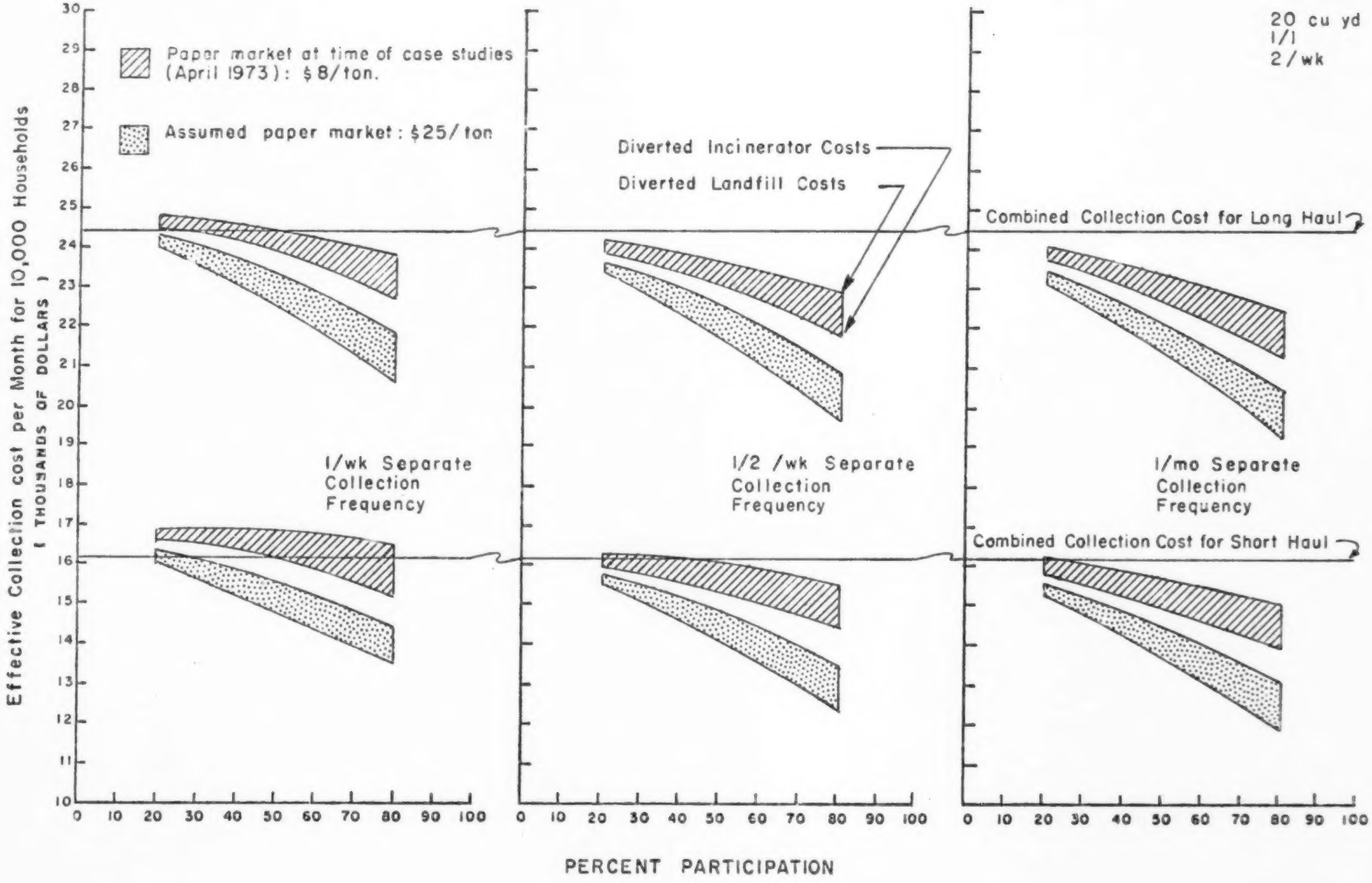

Figure D-8. Impact of optimizing refuse collection operations: exemplary analysis, 1 man mixed refuse collection performed twice per week, 1 man separate collection crew.

APPENDIX E

RACK SYSTEMS ANALYSIS

The analysis to assess the economic impact of rack operations on a mixed refuse collection system incapable of absorbing any incremental time is presented in this appendix. The conceptual rack approach analyzed was modeled after the Madison program: once per week collection of mixed refuse and separated newspaper from the curb; a two man crew; a lugger box transfer system for receipt of newspaper from racks filled prior to the truck body filling with mixed refuse; and 20 cu yd rear-loading compactors with a single 0.9 cu yd rack mounted on the curb side of the truck.

The analysis presented herein was performed using the adapted collection model described in Appendix C.

Data Development

The data used to exercise the model are presented in Table E-1 and discussed in the ensuing text.

Collection vehicle capacity (V_c) was limited to a 20 cu yd compactor. The vehicle costs (C_V) were estimated to be \$4 per hr (\$0.067 per min). The two man crew based on national average labor rates[12], had a total cost (C_c) of \$0.174 per min, including fringe benefits.

The average compacted density of combined refuse (d) with or without newspaper, was assumed at 650 lbs per cu yd. The average quantity of combined refuse per stop (Q) was calculated based on 3.5 persons per residence and 2.5 lbs of solid waste generated per person per day. The resulting average quantity of residential solid waste per stop was estimated to be 61 lbs per week. Assuming 7 lbs of newspaper per household per week, the remaining quantity of combined refuse with all newspaper removed (100 percent participation rate) was 54 lbs. The quantity of combined refuse per collection stop at the exemplary 20,40, and 60 percent participation rates was calculated assuming participating stops generate 54 lbs and non-participating stops generate 61 lbs of combined refuse on a weekly basis.

The average time per stop (t) for collection of mixed refuse prior to separate collection of newspaper was estimated to be 0.49 min using a 2 man crew for once per week collections.[13] The time to collect mixed refuse less

TABLE E-1

DATA FOR EXERCISING THE COLLECTION MODEL -RACK APPROACH-

Variable	Mixed Refuse Collection Only*	Rack Collection/ Percent Participation$^+$			
		20	40	60	100
V_c (cu yd)	20	20	20	20	20
t (min)	0.69	0.70	0.72	0.74	0.78
d (lb/cu yd)	650	650	650	650	650
Q (lbs)	61.0	59.6	58.2	56.8	54.0
B (min)	15	15	15	15	15
D (min)	15.0	18.0	25.1	28.5	40.0
K (min)	120	120	120	120	120
C_v ($/min)	0.067	0.067	0.067	0.067	0.067
C_c ($/min)	0.174	0.174	0.174	0.174	0.174

*Prior to implementation of separate collection.
$^+$After implementation of separate collection.

newspapers was estimated to be 0.45 min. Based on results of a time study performed in San Francisco,[15] the time required to load newspaper into a rack was determined to vary with the rack fill rate. When empty, newspaper bundles were randomly and rapidly tossed into the rack. When the rack was half full (or more) some minor rearranging of bundles was normally performed each time paper was added. As the rack approached about 90 percent of capacity, additional arranging was performed to provide for the last few bundles. Assuming that bundled newspaper stacked in a rack has a density of about 600 lbs per cu yd (accounts for stacking and bundling voids), a rack of 0.9 cu yd capacity will hold the weekly newspaper generation from about 80 households at the assumed generation rate of 7 lbs per week.* Based on the time study and a fill rate of 80 households per rack, the handling times per newspaper bundle are estimated in Table E-2.

TABLE E-2

NEWSPAPER LOADING TIME
-RACK APPROACH-

Rack Capacity* (%)	Loading Time (min/bundle)	Time Applicability*
0-50	6 sec (0.10 min)	first 40 stops
51-90	10 sec (0.17 min)	next 32 stops
91-100	21 sec (0.23 min)	last 8 stops

*Based on 80 stops to fill the rack.

The average time to proceed between collection stops on the route was assumed to be 0.2 min. This time is assumed adequate for stops ranging from 40 to 100 ft apart.

As would be expected, removing recyclable portions of mixed refuse for separate collection increases the number of households that can be served per "mixed truck load." Table E-3 presents the number of households serviced per truck load via the rack approach for each of the assumed participation rates. Based on participation rate, the number of households placing newspaper out for separate collection is also tabulated. The number of racks of newspaper filled per truck load is shown based on the factor of 80 stops per rack.

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*The number of households per rack is, of course, sensitive to fluctuations in the generation rate. For example, during time studies conducted in San Francisco, a rack was filled by newspaper from 30 households.

TABLE E-3

RACK FILL RATE VERSUS PARTICIPATION
-20 CU YD TRUCK-

Participation Rate (%)	Households Per Load, $\frac{(V_c)\ (d)}{Q}$ (no.)	Households Participating (no.)	Newspaper Racks Filled Per Load (no.)
0 (mixed refuse coll'n only)	213	0	0
20	218	44	0.6
40	223	89	1.1
60	229	137	1.7
100	241	241	3.0

Using the number of participating households from Table E-3, the rack fill rate, and the estimated newspaper handling times in Table E-2, the average time per collection stop for rack operations was calculated at the various participation levels as follows:

$$t_j = \frac{1}{S_j} \left\{ (S_j - P_j)\ (t_{m_r}) + (\sum n_{1_{i_j}}) \left[(t_{m_r} - n) + (t_{n_1}) \right] + (\sum n_{2_{i_j}}) \left[(t_{m_r} - n) + (t_{n_2}) \right] + (\sum n_{3_{i_j}}) \left[(t_{m_r} - n) + (t_{n_3}) \right] \right\} + t_{n_s}$$

Where:

t_j = average time per collection stop at participation rate j (min)

S_j = number of collection stops per load at participation rate j (households)

P_j = number of participating households at participation rate j (households)

t_{m_r} = average time per collection stop for mixed refuse (min)

t_{m_r-n} = average time per collection stop for mixed refuse with newspaper removed (min)

n_{1_i} = number of households placing out newspaper bundles contributing to the first 50 percent of rack load i at participation rate j (bundles)

n_{2_i} = number of households placing out newspaper bundles contributing from 51 to 90 percent of rack load i at participation rate j (bundles)

n_{3_i} = number of households placing out newspaper bundles contributing from 91 to 100 percent of rack load i at participation rate j (bundles)

t_{n_i} = average time to load newspaper bundles contributing to the initial 50 percent of a rack load (min/bundle)

t_{n_2} = average time to load newspaper bundles contributing to 51 to 90 percent of a rack load (min/bundle)

t_{n_3} = average time to load newspaper bundles contributing to 91 to 100 percent of a rack load (min/bundle)

t_{n_s} = average travel time between stops on the route (min)

Exercising the preceding equation with participation percentages of 20, 40, 60, and 100 yielded average collection times per stop of 0.70 min, 0.72 min, 0.74 min, and 0.78 min, respectively.

The average one-way driving time between the collection route and the disposal site (B) was assumed to average 15 minutes for the exemplary analysis (i.e., short haul).

The average time spent by the collection vehicle at the disposal site for emptying a full load of mixed refuse (D) was assumed to be 15 min.

Additional time must be included in the disposal time for varying levels of participation associated with rack operations. The number of times a rack would fill while collecting one full load was shown in Table E-3. Based on the fill rate, the number of times that the collection vehicle and crew would be required to leave the collection route to transfer newspapers is presented below:

Participation Rate (%)	Newspaper Racks Filled Per Load (no.)	Trips Required for Newspaper Transfer (no.)
0 (mixed coll'n)	0	0
20	0.6	0
40	1.1	1
60	1.7	1
100	3.0	2

As previously stated, a newspaper transfer operation using lugger boxes was assumed. Lugger boxes are prepositioned each day in the collection area to minimize the off-route haul time. The average round-trip in Madison was about 2 miles and required about 5 min of driving time per transfer. Transfer of newspaper from the rack to the lugger box required an average of 5 min. In addition, the paper rack is unloaded each time the collection vehicle makes a trip to the disposal site. (A lugger box was located at the disposal site for this purpose.) Off-loading time at the disposal site was assumed to be proportional to the amount of newspaper in the rack at the time a full load of mixed refuse was attained. Thus, the times shown in Table E-4 were estimated for dumping operations.

TABLE E-4

ESTIMATED DUMPING TIME: RACK OPERATIONS

Participation Rate (%)	Trips Required to Transfer (no.)	Time for Transfer (min.)		Time to Empty Rack at Disposal Site (min.)	Dumping Time for Mixed Refuse (min.)	Total Dump Time (min.)
		Travel	Off Loading Newspaper			
0 (Mixed coll'n)	0	0	0	0	15	15.0
20	0	0	0	3.0	15	18.0
40	1	5	5	0.1	15	25.1
60	1	5	5	3.5	15	28.5
100	2	10	10	5.0	15	40.0

Non-productive time (K) for such functions as dispatch, lunch and relief, yard to route time, and disposal site to yard time was assumed to total 120 min per day.

Collection vehicles were allowed to return to the route after collecting a full load of refuse if at least 25 percent of another full load could be collected within the working day. No overtime was allowed.

The additional time allocated for collection of a subsequent full or partial load included 15 min to return to the collection area from the disposal site and another 15 min for driving time between the route and the disposal site to dispose of the partial load. Fifteen minutes were again allowed for disposing the partial load.

Impact on Normal Refuse Collection

The collection model was exercised using the data developed above to estimate the total cost of collection operations with and without separate collection via the rack approach.

Due to incremental time requirements for newspaper handling, crews employing the rack method were not capable of serving the same number of households as normal collection crews. Thus, collection costs were increased. However, revenue derived from the sale of separately collected newspaper and from diverted disposal defrays the added collection cost.

Also to be considered in the analysis are the costs for labor and equipment used for collecting the lugger boxes used on the routes for interim paper storage, transporting, dumping, and replacing the boxes on the route for use on the following day. The cost of handling lugger boxes on the collection route was only applicable to the example situation when participation rates exceeded about 35 percent. Lower participation did not require transfer on route as the capacity of the rack was not exceeded during the collection of a full load of refuse. As such, the newspapers were unloaded only at the disposal site prior to dumping the collected refuse.

Based on the case studies, the transfer container for newspaper at the disposal site and subsequent transport was generally provided by the paper stock dealer. Therefore, no costs were assigned to rack operations for these activities.

For participation rates exceeding 35 percent, lugger boxes were required for interim storage. From two to six manhours were required daily in Madison for collecing transferred newspapers from four lugger box containers and prepositioning the containers for the next day's operations. Assuming four man-hrs per day as an average and a cost of \$5.80 per man-hr (the rate of a collection vehicle driver including fringe benefits), the monthly labor costs were estimated to be:

$$\text{Labor cost} = \frac{4\ \text{hr}}{\text{day}} \times \frac{\$5.80}{\text{hr}} \times \frac{21\ \text{days}}{\text{mo}} = \$490/\text{mo}$$

Equipment requirements were based on the assumption that a hoist truck with a 6,000 lb lift capacity and four 10 cu yd lugger boxes would be required for a rack program with over 35 percent participation. Assuming a 6 yr economic life, an initial cost of \$9,000, and \$1,000 per year operating and maintenance costs, the hoist truck costs were estimated to be:

$$\begin{array}{l}\text{Hoist}\\ \text{truck}\\ \text{cost}\end{array} = \frac{\$1{,}500/\text{yr depreciation} + \$1{,}000/\text{yr O \& M}}{12\ \text{mo/yr}} = \$210/\text{mo}$$

Lugger boxes were estimated to cost about \$35 per mo assuming four 10 cu yd boxes with an initial cost of \$550 each, an economic life of 10 yrs, and maintenance costs equalling initial costs over the 10-yr period.

$$\begin{array}{c}\text{Container}\\ \text{costs}\end{array} = \frac{4\ (\$550\ \text{depreciation} + \$550\ \text{maintenance})}{10\ \text{yrs} \times 12\ \text{mo/yr}} = \$35/\text{mo}$$

Therefore, the fully allocated cost to preposition and unload lugger boxes was estimated to total \$735 per month. Of this sum only equipment operational and maintenance costs amounting to \$100 per mo were considered incremental. The hoist truck and lugger boxes were assumed to have been part of the solid waste management equipment inventory prior to implementation so that depreciation costs were not considered incremental. Labor to preposition and collect the lugger boxes in Madison is provided by four collection crewmen (loaders that would normally ride to and from the route) and, therefore, also not incremental.

Revenue for newspapers averaged \$8 per ton at the time of case study. An updated revenue of \$25 per ton was assumed to be more representative of current market prices.

Disposal savings, as developed in Appendix B, were estimated as follows:

Disposal Method	Disposal Savings ($/ton)
Sanitary landfill	
· First-party ownership	0.80
· Second-party ownership	2.50
Incineration	
· First-party ownership	5.35
· Second-party ownership	10.50

Based on the preceding discussion and estimates, the effective rack collection costs per mo for a hypothetical city of 10,000 households is displayed in Figure E-1 reflecting revenue and the extremes of possible disposal cost savings. Also plotted for comparative purposes is the estimated baseline cost for mixed refuse collection prior to implementation of the rack separate collection sub-system (designated "combined refuse collection cost"). The discontinuities shown delineate points where off-route transfer of newspaper are required. At these points (35 and 70 percent participation), a quantum increase in cost is incurred by a collection system unable to absorb incremental time. Curves reflecting revenue at $8 per ton show savings exceeding collection cost only under the circumstances of less than 35 percent participation and second party incinerator disposal savings.

The economic projections with revenue at $25 per ton are more favorable. When participation is less than 35 percent, incremental collection costs are recovered. Incremental costs between 35 and 70 percent were at, or below, a break-even situation, while only savings attributed to diverted incinerator disposal were able to effectively decrease collection costs beyond participation of 70 percent.

The exemplary results shown in Figure E-1 depicted a short haul situation. Changing only the one-way driving time variable (B) in Table E-1 from 15 min to 45 min to portray a long-haul situation resulted in Figure E-2.

The discontinuity at 20 percent participation in the long-haul relationship represents the point where incremental time requirements become so severe that collection trucks are unable to collect more than one full load per day, (i.e., there is not sufficient time for a truck to return to the route for a second or partial load). Economic feasibility in the long-haul example is indicated only at

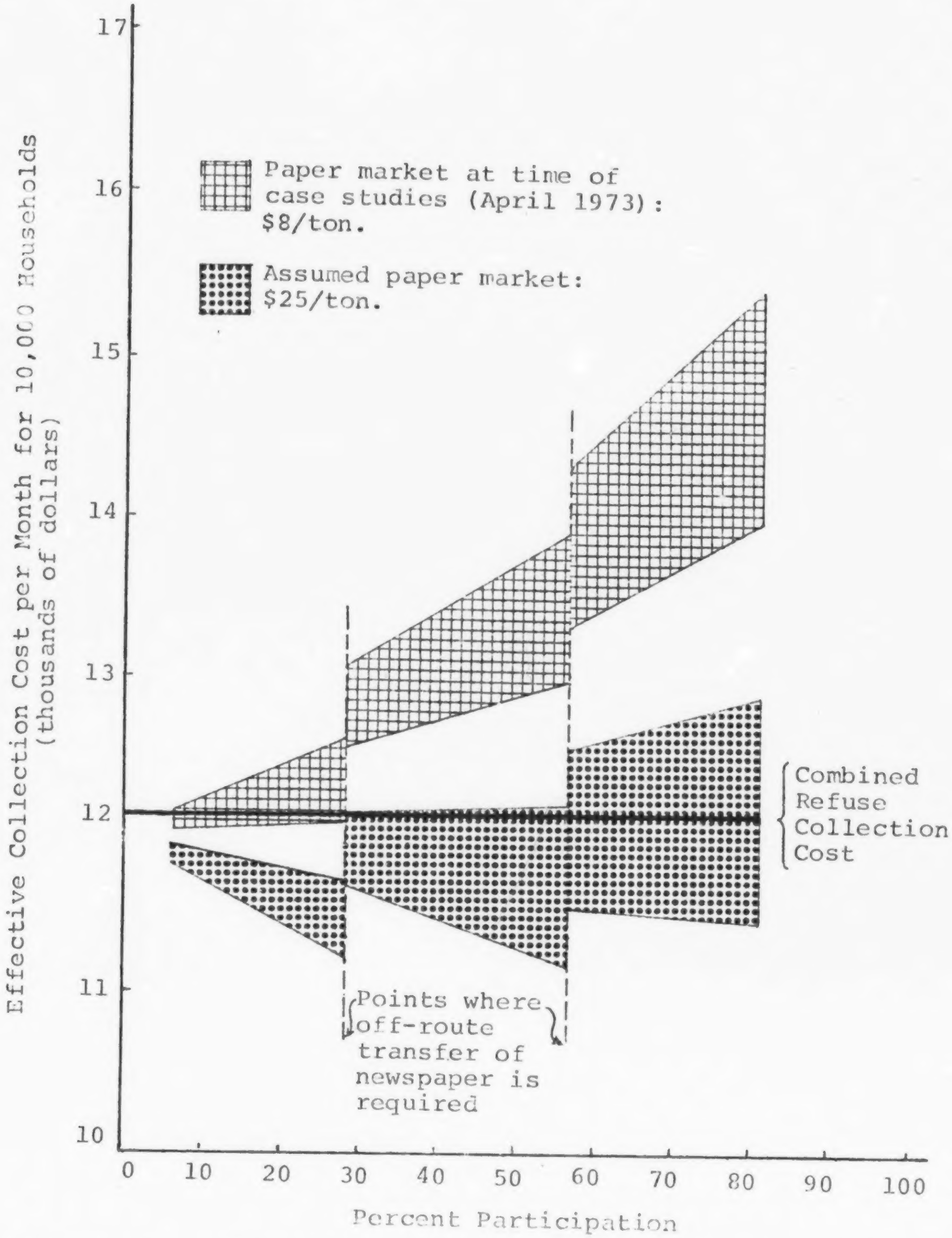

Figure E-1. Effective cost for rack collection of separated newspaper versus combined refuse collection cost prior to system implementation: exemplary analysis for short haul situation.

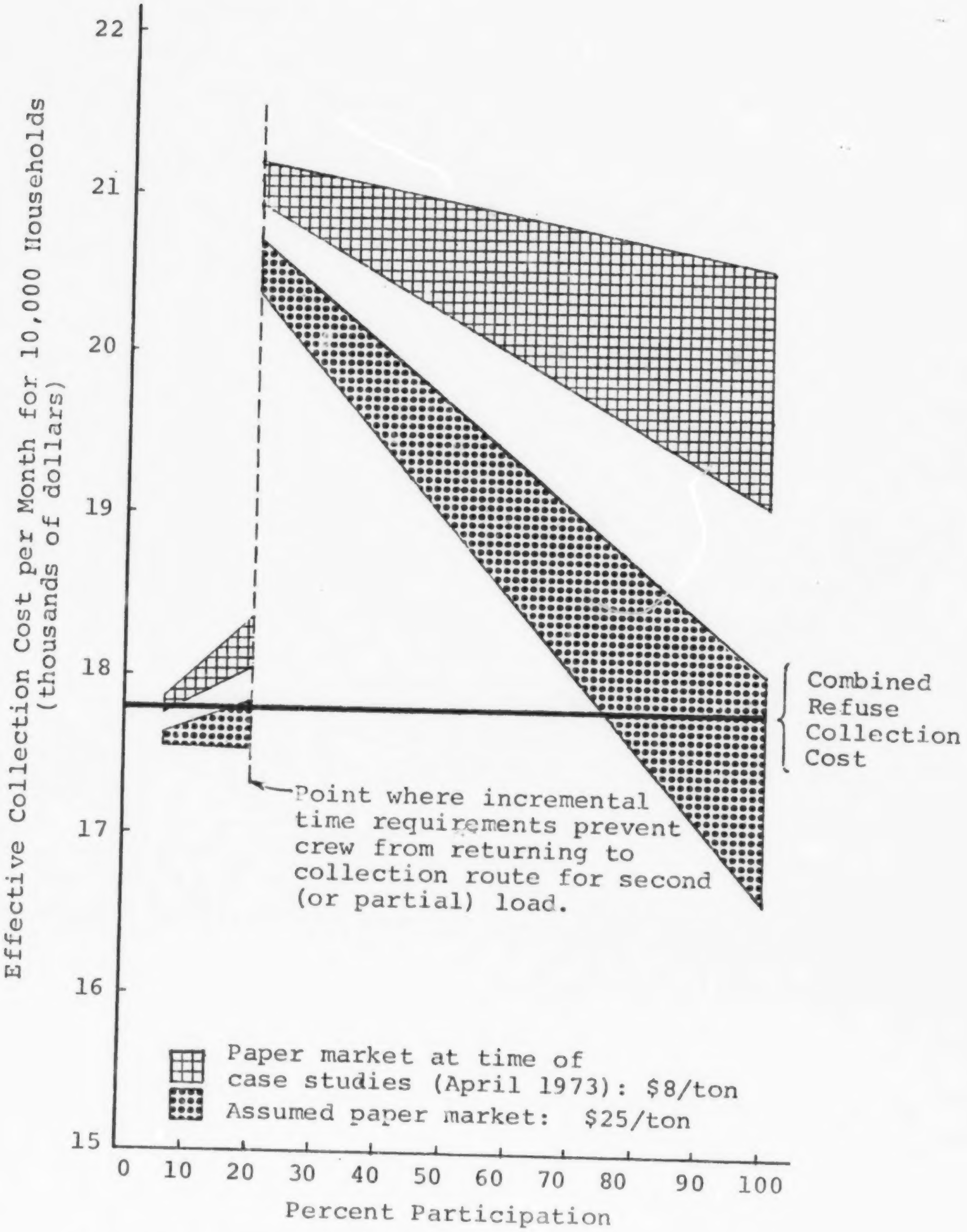

Figure E-2. Effective cost for rack collection of separated newspaper versus combined refuse collection cost prior to system implementation: exemplary analysis for long haul situation.

participation rates less than 20 percent and some situations exceeding 70 percent participation in conjunction with $25 per ton revenue.

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